STATE OF CALIFORNIA
The Resources Agency
Department of Water Resources

BULLETIN No. 164

TEHACHAPI CROSSING DESIGN STUDIES

Book VI

AUGUST 1968

RONALD REAGAN
Governor
State of California

WILLIAM R. GIANELLI
Director
Department of Water Resources

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Director
Department of Water Resources

FOREWORD

Following the decision in May 1966 to adopt the single lift system for pumping the California Aqueduct flow over the Tehachapi Mountains, as substantiated in Books I through V of Bulletin No. 164, the Department immediately focused its attention on procurement of pumps to accomplish this bold feat. The problems of reliability, efficiency, and economy assumed utmost importance in the minds of the designers.

The pumping plant, which will be located at the north base of the Tehachapi Mountains approximately 33 miles south of Bakersfield and about 5 miles east of State Highway 99, is to be constructed in the shape of a "U" with each wing containing 7 pump units. Each of the 14 pumps must be capable of delivering 315 cubic feet per second of flow against a total dynamic head of 1,970 feet. The entire installation is designed to lift 4,100 cubic feet per second a vertical distance of 1,926 feet.

In order to assure that the best value in pumps be attained, including initial cost and future operating cost, which is reflective of efficiency rating, it was decided that a model testing program should be adopted, whereby the model test results would be used in evaluating subsequent contract bids for furnishing and installing the prototype pumps. Daniel, Mann, Johnson, & Mendenhall of Los Angeles, California, was given an extension to their consulting contract to administer the program. The work included preparing the specifications and contracting for construction of the pump models, monitoring the test procedures, and assisting the State in evaluating the test results.

Three American pump manufacturers with their European consorts were prequalified according to normal procedures of the Department, and each was subsequently invited to design and build a competitive pump model. The National Engineering Laboratory of East Kilbride, Glasgow, Scotland, was selected by the Department to perform the independent testing on the models. The results were then held in strict confidence until disclosed at the bid opening for the initial contract to furnish and install seven of the 4-stage pumps. All three manufacturers submitted bids for this initial contract and for the subsequent contract to furnish and install 4 more pumps.

Included in this volume are the important documents substantiating the above activities and placing them on record. Of special note is the decision of the California Water Commission on April 5, 1968, to rename the pump installation, which heretofore had been identified as the Tehachapi Pumping Plant, to A. D. Edmonston Pumping Plant.

William R. Gianelli

William R. Gianelli, Director
Department of Water Resources
The Resources Agency
State of California
June 17, 1968

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CHRONOLOGY OF EVENTS

March 2, 1966	Contractor's prequalification questionnaires were released to all potential bidders.
April 6, 1966	Joint meeting of the Tehachapi Crossing Consulting Board and the DMJM Technical Advisory Board to discuss the pump procurement program in general.
May 12, 1966	Potential bidders informed by the Department of Water Resources (DWR) that construction and testing of a pump model will be prerequisite to bidding on the main procurement contracts.
May 20, 1966	Inspection tour of the National Engineering Laboratory (NEL) in Glasgow, Scotland, by Department of Water Resources engineers.
June 7, 1966	Joint meeting of potential bidders at Motor Columbus Offices in Baden, Switzerland, to reach agreement on model design and test requirements.
June 27, 1966	DWR executed an agreement with Daniel, Mann, Johnson, & Mendenhall (DMJM) of Los Angeles, California, for DMJM to contract with manufacturers for bidders' models; arrange for testing in an independent laboratory; and assist the State in evaluation of the model test results.
June 29, 1966	Model construction and testing contract form and specifications (DMJM 637-1-2) and preliminary technical provisions to procurement contract specifications were issued to potential bidders.
July 1, 1966, and September 29, 1966	The three major design and manufacturing consortia, Allis Chalmers/Sulzer Brothers, Baldwin-Lima-Hamilton/Voith, and Newport News Shipbuilding and Dry Dock/Escher Wyss were officially prequalified by the State to bid on the main pumps.
September 13, 1966	Bidders' conference in Baden to discuss the prototype construction specifications and its influence on design of the models.
September 14 and 15, 1966	Conference with NEL to discuss comparative model testing program.
November 2, 1966	Last of prototype and model designs submitted by potential bidders.
February 17, 1967	DMJM executed contract with NEL to perform comparative tests on manufacturers' models.

March 16, 1967	Draft of NEL Test Procedure sent to potential bidders for review.
April 7, 1967	"Notice to Contractors" issued by the State for furnishing and installing seven vertical centrifugal pumps (Spec. No. 67-24).
May 1, 1967	NEL Test Procedure finalized and issued.
May 21, 1967	Began comparative tests on BLH/Voith model.
June 1, 1967	Completed comparative tests on BLH/Voith model.
June 18, 1967	Began comparative tests on AC/Sulzer model.
June 28, 1967	Completed comparative tests on AC/Sulzer model.
July 9, 1967	Began comparative tests on NN/Escher Wyss model.
August 16, 1967	Completed comparative tests on NN/Escher Wyss model. (Repeat of high speed tests were required. Data obtained prior to July 17 taken as official.)
September 1, 1967	"Notice to Contractors" issued by the State for furnishing and installing four vertical centrifugal pumps (Spec. No. 67-56).
October 4, 1967	Model test results submitted to the State for bid opening.
October 4, 1967	Bids opened for the 7 pump contract (DWR Spec. No. 67-24).
October 18, 1967	Bids opened for the 4 pump contract (DWR Spec. No. 67-56).
November 1, 1967	Notice to proceed on the 7 pump contract issued to Baldwin-Lima-Hamilton/Voith.
November 14, 1967	Notice to proceed on the 4 pump contract issued to Allis Chalmers/Sulzer Bros.

I. PRELIMINARY ACTIVITIES

State of California
The Resources Agency
DEPARTMENT OF WATER RESOURCES

QUESTIONNAIRE

CONTRACTOR'S PREQUALIFICATION FOR FURNISHING AND INSTALLING VERTICAL FOUR-STAGE CENTRIFUGAL PUMPS FOR THE TEHACHAPI PUMPING PLANT

CONTENTS

SCOPE OF PROJECT

SPECIAL PREQUALIFICATION REQUIREMENTS FOR TEHACHAPI PUMPS

QUESTIONNAIRE

A. GENERAL

B. EXPERIENCE RECORD

C. AFFILIATE AGREEMENT

D. MANUFACTURING AND TESTING FACILITIES

E. QUALITY CONTROL

March 1, 1966

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES

CONFIDENTIAL QUESTIONNAIRE TO ACCOMPANY AND BECOME A PART OF CONTRACTOR'S STATEMENT OF EXPERIENCE AND FINANCIAL CONDITION:

SCOPE OF PROJECT:

The Department of Water Resources is contemplating a contract for furnishing and installing 11 vertical motor-driven, four-stage centrifugal pumps for the Tehachapi Pumping Plant on the California Aqueduct. Bids for this contract are scheduled to be opened in June 1966.

Being aware of the outstanding technical skill and experience required for the design and manufacture of the Tehachapi pumps, the Department is requiring all contractors desiring to bid on the Tehachapi pumps to complete this questionnaire as well as the Department's standard Contractor's Statement of Experience and Financial Condition.

If your company is presently prequalified for other work, you will need to complete only this questionnaire. Those companies not presently prequalified will be required to complete both the Contractor's Statement of Experience and Financial Condition and this questionnaire.

In general, the work will include furnishing all labor, materials and equipment, and performing all work necessary in making model tests, completing the design and manufacture, shipment, delivery to the Tehachapi Pumping Plant and installation of 11 vertical four-stage centrifugal pumps. Each pump will have the following rating:

Total Head (rated)	1,970 feet
Flow	315 cfs
Speed	600 rpm
Motor Rating	80,000 hp

A minimum pump efficiency of 91.0 percent will be required.

The motors for the above pumps will be furnished and installed under a separate contract.

SPECIAL PREQUALIFICATION REQUIREMENTS FOR TEHACHAPI PUMPS:

To be prequalified for bidding on the Tehachapi pumps contract, contractors must meet the following special requirements, in addition to the general prequalification requirements set forth in the Statement of Experience and Financial Condition, and shall demonstrate compliance with such special requirements in the manner set forth below:

(1) The contractor, or an affiliate of the contractor to be employed on the Tehachapi pumps contract, shall have designed, model tested and installed raw water pumps having two or more stages. Each pump shall have a head per stage of at least 300 feet, a rated power input of at least 20,000 horsepower, and a capacity of at least 100 cfs. Such pumps shall have been installed and have been in successful operation in at least four plants for at least two years. The contractor shall demonstrate compliance with these requirements by completing the pertinent portions of the attached questionnaire, showing the experience of his firm or that of an affiliate, as the case may be. The affiliate may be a foreign firm.

(2) If the contractor relies upon the experience of an affiliate to meet the requirements of (1) above, that affiliate shall have entered into a contract with the contractor to perform design and supervisory work on the Tehachapi pumps contract. The contractor shall demonstrate compliance with this requirement by furnishing a copy of such contract to the Department with the attached questionnaire. (See Section C of this questionnaire.)

(3) If the contractor relies upon the experience of an affiliate to meet the requirements of (1) above, then the contractor's firm, without the aid or participation of an affiliate, shall have designed, model tested, manufactured and installed single stage type pumps, or pump-turbines with heads of at least 350 feet and a power rating of at least 25,000 horsepower, or shall have designed, model tested, manufactured and installed Francis turbines with a horsepower rating of at least 50,000 horsepower. Such pumps or turbines shall have been installed and have been in successful operation in at least four plants for at least two years. The contractor shall demonstrate compliance with these requirements by completing the pertinent portions of the attached questionnaire.

QUESTIONNAIRE

A. General

1. Firm Name ______________________________

2. Home Office Address ______________________________

____

____

3. California State Contractor's License No. ______________________

4. Affiliate's Name and Address ______________________________

____

____

5. Attach an Organization Chart for your company.

6. Attach an Organization Chart for your affiliate.

7. Give a listing of names and titles of the Project Manager and Principal Engineers of your firm who will work on the Tehachapi pump contract.

8. Give a listing of names and titles of the Project Manager and Principal Engineers of your affiliate firm who will work on the Tehachapi pump contract.

9. Give the location(s) of your major manufacturing facilities that would be used for this project and the total number of employees at each location.

B. Experience Record

Please fill in the information indicated in Table I for at least four raw water centrifugal pumps designed or manufactured by your company or your affiliate having two or more stages. Each pump shall have a head per stage of at least 300 feet, a rated power input of at least 20,000 horsepower, and a capacity of at least 100 cfs. Such pumps shall have been installed and have been in successful operation in at least four plants for at least two years.

If the experience of an affiliate was used to fill in Table I, the contractor is required to fill in the information indicated in Table II for at least four single-stage raw water centrifugal pumps and pump-turbines with heads of at least 350 feet and having a rated power input of 25,000 horsepower or greater that were designed or manufactured by the contractor, or the contractor is required to fill in the information indicated in Table III for at least four Francis turbines having a rated power output of 5 0,000 horsepower or greater that were designed or manufactured by the contractor. Such pumps or turbines shall have been installed and in successful operation in at least four plants for at least two years. The experience of your affiliate should not be included in Tables II and III.

The following additional instructions are given regarding Item 5 listed in Tables I, II and III.

Item 5, Unit Type

a. Table I - Indicate number of stages, single or double, flow, and horizontal or vertical shaft. Examples: 4SV means 4-stage, single-flow, vertical; 2DH means 2-stage, double-flow, horizontal.

b. Table II - Indicate pump or pump-turbine, single or double-flow, and horizontal or vertical shaft. Examples: PDH means pump, double-flow, horizontal; PTSV means pump-turbine, single-flow, vertical.

c. Table III - Indicate horizontal or vertical shaft as H or V, respectively.

C. Affiliate Agreement

Attach a copy of your formal agreement with your affiliate. The financial sections or provisions of this agreement need not be included.

The formal agreement between the contractor and an affiliate shall be binding for a period of time at least equal to the duration of the Tehachapi pump contract plus the guarantee period and shall provide as a minimum that the affiliate be responsible for the following:

a) Basic hydraulic and mechanical design.

b) Detailed design or approval of detailed design.

c) Assignment of a responsible representative to the prime contractor's shop during manufacturing and shop testing and during erection and site testing.

D. Manufacturing and Testing Facilities

1. Laboratory and Testing Facilities (Prime and/or Affiliate)

a) Describe laboratory and model testing facilities and give their location.

b) What testing, if any, would be contracted out for this contract? Name and describe firms who would be engaged.

Note: For model testing, the contractor will need a 2,000 horsepower dynamometer with drive speed capability up to about 3,000 rpm. Gear drives suitable for required test speeds may be employed if a continuously variable speed dynamometer is unavailable.

c) Indicate that you possess (or have at your disposal) such a dynamometer as is described above or show a satisfactory plan for providing such a dynamometer. Subcontracting model testing to an independent laboratory is permissible.

2. <u>Manufacturing Facilities</u> (Prime only)

a) Equipment - List all large equipment available in your manufacturing facilities which will be used on work for the Department; including machine tools, balancing equipment, furnaces for heat treatment, etc. A standard facilities brochure if it is complete and adequate - or supplement as necessary - may be submitted in lieu of this list.

Quantity	Description of Equipment	Size	Remarks

b) Give proposed source or sources of principal castings and forgings:

Part	Material	Source
(1) Pump Casings	Cast Steel	____________
(2) Impellers	Stainless Steel	____________
(3) Diffusers	Stainless Steel	____________
(4) Shaft	Carbon Steel	____________

c) Mark with an (X) those main pump parts which would be completely machined and heat treated in your own workshop:

Item	Approximate Dimension	Machining	Heat Treatment
Pump Casing	10' O.D. x 10'	( )	( )
Pump Impeller	6' O.D. x 20"	( )	( )
Shaft	2' O.D. x 25'	( )	( )

d) Show where the work referred to in c) above will be performed if not accomplished in your plant.

E. Quality Control

1. Do you have a formal quality control program?

   ( ) Yes   ( ) No

   If yes, attach a copy of your quality control manual.

2. Supply the following information covering your quality assurance provisions, inspection methods and quality control. If the information is contained in your quality control manual, give the section title and page number in the manual.

   a) Show by an organization chart the relationship between your quality control department and the engineering, production and testing departments. If organization is detailed sufficiently in Section A.5, page 4, the organizational chart need not be repeated here.

   b) Describe your procedures for calibrating and maintaining manufacturing gauges and instruments.

      (1) Present established schedules for maintenance and recalibration.

      (2) What are your rules applying to calibration of gauges and instruments.

c) Give a brief description of your inspection procedures with reference to:

(1) Receiving inspection of purchased components and materials.

(2) Inspection of work in process.

(3) Final inspection.

d) Describe the training given to your inspectors and the methods employed to rate them. Describe instruction methods used for inspectors for a particular job.

e) Mark with an (X) the test methods which are used in your manufacturing plant as <u>standard</u> test procedure for large hydraulic machinery and for which skilled personnel and equipment is available:

( ) Tensile Test

( ) Chemical Analysis

( ) Hardness Test

( ) Radiographic Tests

( ) Magnetic Particle Inspection

( ) Dye - Penetrant Inspection

( ) Notch Tests

( ) Fatigue Tests

( ) Other ______________________________

FIRM: ______________________________

TABLE I.: TWO OR MORE STAGE CENTRIFUGAL PUMP EXPERIENCE OF CONTRACTOR AND/OR AFFILIATE

1. PLANT NAME						
2. PLANT LOCATION						
3. OWNER'S NAME AND ADDRESS						
4. NUMBER OF UNITS						
5. UNIT TYPE						
6. YEAR EACH UNIT WAS INSTALLED						
7. TOTAL DYNAMIC HEAD, FEET						
8. CAPACITY, cfs						
9. SPEED, rpm						
10. POWER, HORSEPOWER						
11. IMPELLER DIAMETER, INCHES						
12. PUMP DESIGN BY (FIRM AND LOCATION)						
13. PUMP MANUFACTURED BY (FIRM AND LOCATION)						
14. PUMP INSTALLATION (OWN CREWS, FURNISHED ERECTION ENGINEERS, OR SUBCONTRACT)						
15. OPERATION AND MAINTENANCE INSTRUCTION? (YES OR NO)						
16. WAS A MODEL TEST CONDUCTED? (YES OR NO)						
17. WAS A FIELD EFFICIENCY TEST MADE? (YES OR NO)						
18. AVERAGE OPERATING HOURS PER UNIT TO DATE						
19. APPROXIMATE AVERAGE NUMBER OF STARTS PER UNIT TO DATE						

FIRM: ____________________

TABLE II.: SINGLE STAGE PUMP AND PUMP-TURBINE EXPERIENCE OF PRIME CONTRACTOR

1. PLANT NAME						
2. PLANT LOCATION						
3. OWNER'S NAME AND ADDRESS						
4. NUMBER OF UNITS						
5. UNIT TYPE						
6. YEAR EACH UNIT WAS INSTALLED						
7. TOTAL DYNAMIC HEAD, FEET						
8. CAPACITY, cfs						
9. SPEED, rpm						
10. POWER, HORSEPOWER						
11. IMPELLER DIAMETER, INCHES						
12. PUMP DESIGN BY (FIRM AND LOCATION)						
13. PUMP MANUFACTURED BY (FIRM AND LOCATION)						
14. PUMP INSTALLATION (OWN CREWS, FURNISHED ERECTION ENGINEERS, OR SUBCONTRACT)						
15. OPERATION AND MAINTENANCE INSTRUCTION? (YES OR NO)						
16. WAS A MODEL TEST CONDUCTED? (YES OR NO)						
17. WAS A FIELD EFFICIENCY TEST MADE? (YES OR NO)						
18. AVERAGE OPERATING HOURS PER UNIT TO DATE						
19. APPROXIMATE AVERAGE NUMBER OF STARTS PER UNIT TO DATE						

FIRM: ______________________________

TABLE III.: FRANCIS TURBINE EXPERIENCE OF PRIME CONTRACTOR

1. PLANT NAME						
2. PLANT LOCATION						
3. OWNER'S NAME AND ADDRESS						
4. NUMBER OF UNITS						
5. UNIT TYPE						
6. YEAR EACH UNIT WAS INSTALLED						
7. HEAD, FEET						
8. CAPACITY, cfs						
9. SPEED, rpm						
10. POWER, HORSEPOWER						
11. RUNNER DIAMETER, INCHES						
12. TURBINE DESIGN BY (FIRM AND LOCATION)						
13. TURBINE MANUFACTURED BY (FIRM AND LOCATION)						
14. TURBINE INSTALLATION (OWN CREWS, FURNISHED ERECTION ENGINEERS, OR SUBCONTRACT)						
15. OPERATION AND MAINTENANCE INSTRUCTION? (YES OR NO)						
16. WAS A MODEL TEST CONDUCTED? (YES OR NO)						
17. WAS A FIELD EFFICIENCY TEST MADE? (YES OR NO)						
18. AVERAGE OPERATING HOURS PER UNIT TO DATE						
19. APPROXIMATE AVERAGE NUMBER OF STARTS PER UNIT TO DATE						

State of California
The Resources Agency
DEPARTMENT OF WATER RESOURCES

EVALUATION FORM

CONTRACTOR'S PREQUALIFICATION FOR FURNISHING AND INSTALLING VERTICAL FOUR-STAGE CENTRIFUGAL PUMPS FOR THE TEHACHAPI PUMPING PLANT

PART I - Mandatory Requirements	Yes	No
Item 1. The Contractor has established compliance with the minimum experience requirements as specified in the questionnaire.		
Item 2. The Contractor has a satisfactory detailed agreement with the affiliate whose experience is utilized in complying with Item 1, as shown by the answers to Section C.		
Item 3. The prime contractor has demonstrated general experience in the field of large hydraulic machinery as specified in the questionnaire.		
If there is a "No" answer to any of these items, the Contractor will be disqualified.		

PART II - Questionnaire Rating

A. INSTRUCTIONS

1. General

The attached questionnaire is designed to determine the qualifications of prospective contractors for supplying pumps for the Tehachapi Pumping Plant. This evaluation form is to be used to evaluate contractors on a uniform basis and determine that they meet the minimum requirements set forth in the questionnaire.

2. Evaluation Procedure

The General section (Section A) of the questionnaire is for information only and is not graded.

Section B - Table 1, Section B - Tables II and III, Section C, Section D and Section E will be graded individually and a passing grade of 80 must be obtained on each section.

B. GRADING OF SECTION B, EXPERIENCE RECORD

EVALUATION OF TABLE I

For each different pump installation:

1. Give 30 points if all answers satisfactorily meet minimum conditions.
2. Take off 5 points if Row 6 answer is later than 1963.
3. Take off 2 points if Row 14 answer is "subcontract" and/or if Row 15 answer is "No".
4. Take off 2 points if one or both of the answers to Row 16 and 17 is "No".
5. Take off 5 points if the answer to Row 18 is less than 5,000 hours.

Total the 4 highest scores for all the installations listed.

Score for Table I

Installation No.	Score
I	________
II	________
III	________
IV	________
Total	________
	________

The total must be 80 out of a possible 120.

Evaluation of Tables II and III

For each different pump or turbine installation (either Table II or Table III).

1. Give 30 points if all answers satisfactorily meet maximum requirements.
2. Take off 5 points if Row 6 answer is later than 1963.
3. Take off 2 points if Row 14 answer is "subcontract" and/or Row 15 answer is "No".
4. Take off 2 points if one or both of the answers to Row 16 and Row 17 is "No".
5. Take off 5 points if the answer to Row 18 is less than 5,000 hours.

Total the 4 highest scores for all installations listed on Tables II and III.

Installation No.	Score
I	________
II	________
III	________
IV	________
Total	________
	________

The total must be 80 out of a possible 120.

C. GRADING OF SECTION C, AFFILIATE AGREEMENT

For each "Yes" answer, give points indicated.

Question	Score	Points
a)	________	22
b)	________	22
c)	________	22
d)	________	22
e)	________	12
Total	________	
	________	

The score must be 80 out of a possible 100.

D. MANUFACTURING AND TESTING FACILITIES

	Yes	Maybe	No	Item Point Score
1. The contractor has adequate manufacturing facilities to complete the work.	22	11	0	
2. The contractor has adequate plant space, crane facilities, and other facilities to assemble and test the prototype.	22	11	0	
3. The contractor has adequate facilities to perform model tests, in-process tests, and final tests.	22	11	0	
4. The contractor has adequate shop supervisory personnel.	22	11	0	
5. Laboratory facilities owned or available are sufficient in quantity and quality to assure maintenance of test instruments, and the performance of adequate tests of materials raw or processed.	6	3	0	

	Yes	Maybe	No	Item Point Score
6. Material, on receipt, is handled in a manner to preclude damage or deterioration.	4	2	0	
7. The contractor has completed the questionnaire as required.	2	1	0	
E. QUALITY CONTROL				
1. Contractor's quality control group has authority to enforce its decisions.	16	8	0	
2. Inspection records are maintained and available for perusal by state personnel.	16	8	0	
3. The contractor has an adequate quality assurance program.	10	5	0	
4. The contractor's quality control group is functionally separated from production.	8	4	0	
5. The contractor's inspection personnel are adequate in both skill and number.	8	4	0	
6. There is a satisfactory "in-process" inspection system.	8	4	0	
7. Acceptance and rejection criteria are specified.	8	4	0	
8. There is adequate incoming inspection of items not inspected at sources.	8	4	0	
9. Material, on receipt, is handled in a manner to preclude damage or deterioration.	8	4	0	

	Yes	Maybe	No	Item Point Score
10. Laboratory facilities owned or available are sufficient in quantity and quality to assure maintenance of test instruments, and the performance of adequate tests of materials raw or processed.	6	3	0	
11. Contractor has a plan for training inspectors assigned to an unfamiliar job.	2	1	0	
12. The contractor has completed the questionnaire as required.	2	1	0	

LETTER TO POTENTIAL BIDDERS
REGARDING MANUFACTURE AND TESTING OF PUMP MODELS

May 12, 1966

Newport News Shipbuilding
and Dry Dock Company
Newport News, Virginia

Attention: Mr. G. T. Abernathy

Subject: Procurement - Tehachapi Pumps

Gentlemen:

As a result of information furnished by you and other manufacturers in response to our recent inquiry regarding bidding procedures for furnishing and installing pumps for the Tehachapi Pumping Plant, I have decided to proceed on the basis of bidder's models for procurement of these pumps.

The pump procurement procedure will be divided into two separate phases. The first phase will be for designing, manufacturing and testing a bidder's model and the second will be for manufacturing and installing the prototype pumps.

Under the first phase, service agreements at a fixed price to be determined by the Department will be issued for design, construction, and testing of a model and preparing a final report of the model test results to be submitted with the prototype bid proposals. These service agreements will be issued only to those firms which have prequalified for design, manufacture, and installation of the prototype pumps according to our procedures which have already been furnished to you. Complete technical specifications for the prototype pump, the model, the laboratory, and testing procedures will be in this service agreement. To ensure comparabilit for the purpose of these tests each manufacturer's laboratory will be calibrated and standardized by a representative of the State. All tests utilized in the final report will be witnessed by the State. The results of these tests will be used for determination of the low evaluated bid.

The service agreement will provide that, at the option of the State, the model may be tested at an independent testing laboratory selected by the State subsequent to testing in the manufacturer's laboratory as described in the preceding paragraph. Each manufacturer will be authorized to have a representative present at the laboratory when his model is being installed and tested. If this option is exercised, the test results of the independent laboratory will be used to determine the low evaluated bid.

The second phase will include the final design, manufacture and installation of eleven pumps. Shortly before termination of the first phase, advertisement will be issued for competitive bids for this work. For purpose of comparison of bids, from each bid price there will be deducted $330,000 times the number of tenths of percent by which the efficiency of the bidder's model, tested under the first phase, exceeds 91.0 percent. The bidder having the low bid when so evaluated will be awarded the contract for the work under the second phase. The efficiencies referred to are those determined in the laboratory for the model pump stepped up to the prototype by the scale ratio according to the step-up formula set forth in the specifications.

The contract specifications for the second phase will repeat substantially unchanged the specifications for the prototype pump as in the service agreement for the first phase. The specifications will also require that the pumps be manufactured in exact homologous configuration to the model which the bidder produced under the first phase and which formed the basis for the test report submitted with his bid.

The following is our anticipated schedule for accomplishing the work as outlined above:

(1) Issue service agreement for model work - July 1, 1966

(2) Complete model work, including testing in manufacturer's laboratory - July 1, 1967

(3) Advertise prototype pumps - April 23, 1967

(4) Open prototype bids - June 16, 1967

(5) Notice to proceed for prototype contract - October 13, 1967

(6) Completion of installation of first pump - October 9, 1970.

The foregoing schedule does not include additional time required if the State should exercise its option for tests in an independent laboratory. It is expected that such tests would require a period of seven months which would be inserted immediately after item (2) in the above schedule with a like postponement of all subsequent items.

Will you please furnish to us at the earliest possible date your best estimate of the cost of designing, manufacturing, and testing in your own laboratory of the pump models according to the procedure described hereinbefore. The amount payable under the service agreement, which will be uniform for all bidders, will be sufficient to cover substantially all costs of this work; at the same time it should be understood that a minor part of these costs may have to be borne by the bidder as part of his normal bidding costs.

Any other pertinent and timely comments which you wish to make relative to the procedure outlined in the foregoing will be appreciated and will be carefully considered.

Sincerely yours,

Alfred R. Golzé

Alfred R. Golze'
Chief Engineer

DPThayer:cp
cc: J.A.Wineland
T.W.Troost

This same letter sent to: Baldwin-Lima-Hamilton Corp.
Allis-Chalmers Mfg. Co.

DMJM

DANIEL, MANN, JOHNSON, & MENDENHALL
3325 WILSHIRE BLVD. · LOS ANGELES 5, CALIFORNIA · DUNKIRK 1-3663
PLANNING § ARCHITECTURE § ENGINEERING § SYSTEMS

CONFIRMATION NOTICE No. 19

TO: Mr. Alfred R. Golze', Chief Engineer
Resources Agency of California
Department of Water Resources
P. O. Box 388
Sacramento 2, California

SUBJECT · THIS IS TO CONFIRM verbal conversations with DWR during the period May 15 to May 21, 1966.

DATE May 26, 1966

OUR JOB NO 637-1-1 Contract - DWR 352876

Regarding Project Tehachapi

Parties to Discussion Mr. Warne, Director (DWR), Mr. Golze' (DWR), Mr. Dewey (DWR), Mr. Miller (DMJM), Mr. Bowerman (DMJM)

It was agreed that DMJM would administer the fabrication and testing of bidders models for the Tehachapi pump procurement. This work would consist of the following basic elements.

A. Model Contracts

1. Notify prequalified bidder of model program.

2. Prepare a model and model test specification.

3. Receive prices and schedules from bidder and negotiate an equal price for all bidders and a maximum rate schedule for delivering models. Premium pay to a bidder for an accelerated delivery schedule is to be considered.

4. Execute model contracts - target date for starting work is July 1, 1966.

5. Receive and review prototype design.

6. Approve models.

7. Check out bidder test labs for "in house" testing.

8. Monitor manufacturer's testing.

COPIES TO
Donald Thayer (DWR)
T. W. Troost (DWR)
D. R. Miller (DMJM)
S. Svendsen (DMJM)
S. Magota (DMJM)

DANIEL, MANN, JOHNSON & MENDENHALL

BY Ralph Bowerman

B. Comparative Testing

1. Develop testing program and specifications.
2. Determine details of NEL testing capability.
3. Receive quotation from NEL.
4. Execute contract with NEL.
5. Expedite the shipping of models to NEL and the installation of models.
6. Monitor comparative tests for H, Q, efficiency and cavitation.
7. Analyze test results.
8. Report and certify efficiencies.
9. Arrange travel of department personnel witnessing comparative tests.

C. Pump Procurement

1. Finalize Tehachapi pump procurement specifications.
2. Assist in analysis of bids.

As this work is critical to the schedule for meeting water delivery dates, DMJM will proceed immediately.

Within the next few days, a formal proposal for this work with a detailed budget and schedule will be prepared and submitted to the Department for approval and use in preparing a contract amendment. Included in the proposal will be a graphic panel and working model of a Tehachapi pump to be used for demonstrating the operation of the plant. Work steps will be:

1. Formulate requirements.
2. Commission design of working model.
3. Design graphic display panel.
4. Prepare procurement specification for graphic display panel and working model.

FORM 2—APPROVED BY THE ATTORNEY GENERAL (REV. 10-56)

CONTRACTOR—( )

STATE AGENCY—( )

DEPT. OF FINANCE—( )

CONTROLLER—( )

STATE OF CALIFORNIA
STANDARD AGREEMENT

NUMBER 352876
AMENDMENT V

THIS AGREEMENT, Made and entered into this 21th day of June, 19 66, at Sacramento, County of Sacramento, State of California, by and between State of California, through its duly elected or appointed, qualified and acting

DIRECTOR (Title of officer acting for State) DEPARTMENT OF WATER RESOURCES (Department or other agency)

hereinafter called the State, and

DANIEL, MANN, JOHNSON & MENDENHALL

hereinafter called the Contractor.

WITNESSETH: That the Contractor for and in consideration of the covenants, conditions, agreements, and stipulations of the State hereinafter expressed, does hereby agree to furnish to the State services and materials, as follows:

(Set forth service to be rendered by Contractor, amount to be paid Contractor, time for performance or completion, and attach plans and specifications, if any.)

WHEREAS: Contractor and State entered into a contract for research and development on July 15, 1963, for Tehachapi Pumping Plant;

WHEREAS: The State has decided to have prospective pump suppliers furnish bidder's models;

WHEREAS: The State desires that the Contractor not only continue with studies heretofore agreed upon, but in addition, negotiate contracts with manufacturers for furnishing bidder's models; making arrangements for testing such models in an independent testing laboratory; and assisting the State in the evaluation of the model test results for evaluation of the prototype pump bids;

NOW THEREFORE, it is agreed that certain Service Agreement No. 352876 dated July 15, 1963, as amended by Amendment No. I thereto,

State Personnel Board
John McCoy 6/23/66

The provisions on the reverse side hereof constitute a part of this agreement.

IN WITNESS WHEREOF, This agreement has been executed, in quadruplicate, by and on behalf of the parties hereto, the day and year first above written.

STATE OF CALIFORNIA

DEPARTMENT OF WATER RESOURCES
(Name of State agency)

By Neely Gardner

Deputy Director Administration
(Title)

Contractor Daniel, Mann, Johnson & Mendenhall
(If other than an individual, state whether a corporation, partnership, etc.)

By Irvan Mendenhall

President
(Title)

3325 Wilshire Boulevard
Los Angeles, California
(Address)

(Continued on sheets, each bearing name of Contractor)

DO NOT WRITE IN THIS SPACE

...nt of General Ser...
Approved
...ne 27, 1966
...bert Harlner
Director

Approved
... W Black
...ept of Finance

Disbursement from ~~WRRF Budget Act of 1966~~ Fund Item Ch

Reimbursement from ~~CWRDEF SWP other~~ Fund Item Ch 1762/59 Code 437

F.Y.	Account No.		Organ. No.	Exp. Code	Budget Item No.	Encumbrance Amount	Unenc. Bal.
67	4573	5001	3440	228		250,000.00	330,000.00
68	9050	4573	3440	228		450,000.00	-0-

I Hereby Certify upon my own personal knowledge that the unencumbered balance of the departmental budget provision for the period stated above is correct.

(After T.B.A. No. or B.R. No.)

Edward J Horton
SIGNATURE OF ACCOUNTING OFFICER

6/22/66
DATE

27

DWR 627 (REV. 4-62) FUNDING STRIP

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES 50211-950 7-65 10M QUIN OSP

dated February 14, 1964; by Amendment No. II thereto, dated May 5, 1964; by Amendment No. III thereto, dated September 1, 1965; and by Amendment No. IV thereto, dated May 10, 1966; by and between the parties hereto is hereby amended as follows:

1. Section 9, as amended is further amended to increase the total amount to be paid the Contractor from not to exceed $1,420,800 to not to exceed $2,120,800.

2. Section 10, as amended, is further amended to provide that all services required to be performed by the Contractor shall be completed on or before October 31, 1967.

3. Except as herein amended, all terms and conditions of the contract as previously amended shall continue in full force and effect.

1. The State hereby agrees to pay for the services and materials at the times, in the manner and for the consideration, herein expressed.

2. The Contractor agrees to indemnify and save harmless the State, its officers, agents and employees from any and all claims and losses accruing or resulting to any and all contractors, subcontractors, materialmen, laborers and any other person, firm or corporation furnishing or supplying work, services, materials or supplies in connection with the performance of this contract, and from any and all claims and losses accruing or resulting to any person, firm or corporation who may be injured or damaged by the Contractor in the performance of this contract. The Contractor shall provide necessary workman's compensation insurance at Contractor's own cost and expense.

3. The parties hereto agree that the Contractor, and any agents and employees of Contractor, in the performance of this agreement, shall act in an independent capacity and not as officers or employees or agents of State of California.

4. The State may terminate this agreement and be relieved of the payment of any consideration to Contractor should Contractor fail to perform the covenants herein contained at the time and in the manner herein provided. In the event of such termination the State may proceed with the work in any manner deemed proper by State. The cost to the State shall be deducted from any sum due the Contractor under this agreement, and the balance, if any, shall be paid the Contractor upon demand.

5. This agreement is not assignable by Contractor either in whole or in part.

6. Time is of the essence of each and all the provisions of this agreement, and the provisions of this agreement shall extend to and be binding upon and inure to the benefit of the heirs, executors, administrators, successors, and assigns of the respective parties hereto.

7. It is mutually understood and agreed that no alteration or variation of the terms of this contract shall be valid unless made in writing and signed by the parties hereto, and that no oral understandings or agreements not incorporated herein, and no alterations or variations of the terms hereof unless made in writing between the parties hereto shall be binding on any of the parties hereto.

II. BUILDING AND TESTING OF BID MODELS

PROCEDURES

agreed upon in a

JOINT MEETING

held at Motor-Columbus Offices
Baden, Switzerland on June 7, 1966

Participants:

Newport News	- R.M.	Donaldson	- Indust. Prod. Eng.
Escher Wyss	- W.	Meier	- Chief Hydr. Eng.
	- W.	Lecher	- Hydr. Eng.
	- C.	Battegay	- Chief Eng.
Allis Chalmers	- D.J.	Waalkes	- Prod. Eng.
Sulzer Bros.	- D.	Floriancic	- Chief Hydr. Eng.
	- Dr.H.	Thomae	- Test Eng.
Baldwin-Lima-Hamilton	- J.M.	White	- Mgr. Engineering
Voith	- Dr.R.	Dziallas	- Chief Hydr. Eng.
	- H.	Offenhäuser	- Test Eng.
	- H.	Schleicher	- Project Mgr.
Daniel, Mann, Johnson & Mendenhall	- H.	Gartmann	- Project Eng.
Motor-Columbus	- P.	Jaray	- Chief Eng. (part time)
	- O.	Hartmann	- Project Eng.
	- J.	Pillet	- Test Eng. (part time)
as observers on behalf of Bechtel	- H.	Gerber	- Professor ETH
	- L.C.	Neale	- Professor ARL

1. INTRODUCTION

It is the intention of the Department of Water Resources (DWR), State of California, to use the model efficiency in evaluating the bids on the 4-stage pumps for the Tehachapi pumping plant. Therefore, each qualified bidder is requested to build and test a complete 4-stage pump model. Finally, the models will undergo comparative testings at National Engineering Laboratory (NEL) at East Kilbride, Scotland. The model efficiency measured at NEL will be used for the prototype bid evaluation.

DWR has entrusted Daniel, Mann, Johnson and Mendenhall (DMJM) of Los Angeles, California, with conducting the model work. DMJM will place the orders for the bidders' models with three qualified US-firms. The actual design, manufacture and testing of the models will be done by the respective European affiliate firms.

2. PURPOSE OF MEETING

Motor-Columbus, associate consultant of DMJM, has in previous meetings with Escher Wyss (May 26), Voith (May 27) and Sulzer (June 1) discussed the problems involved in the model design and testing procedures. It is the purpose of the present meeting to reach agreement between all parties concerned in the model design and test requirements, so that firms can begin the design work.

3. QUALIFICATION

The qualification procedure is not yet completed. It will require further discussions between European and US affiliate firms, DWR and DMJM. For the purpose of this meeting, it shall be assumed that these legal and commercial problems will be solved in due time.

4. LETTER OF INTENT AND SPECIFICATION

In this meeting the technical requirements were clarified. Firms are now preparing their price suggestions.

For each bidder the price shall include the design of the prototype and model pump, manufacturing the model and testing the model in the firms' own laboratories (to the extent stated below), sending one mechanic and one authorized test engineer to NEL for the comparative testing for a period of one month, and air freight shipment of model to NEL and back, including insurance.

DMJM will negotiate the price with the US-firms and then issue Letters of Intent to the US-firms, with copy to the European affiliates. The date of the Letter of Intent will constitute the date of the order to proceed.

As soon as possible, DMJM will issue the final model specification. The decisions of this meeting will form the basis for the technical part of the specification.

In case the model contract as outlined in the Letter of Intent should not become effective, DMJM shall pay each bidder 10 % of the contract price stated in the Letter of Intent for each month between the date of the Letter of Intent and the date of notice of cancellation. Payment for fractions of a month shall be prorated.

5. TIME SCHEDULE

It is recognized that time is of essential importance in the whole bidder's model procedure. DWR has requested that bidders' models shall be ready for release to NEL comparative testing by March 1967. The firms are carefully considering all possibilities to comply with this request and will provide final information shortly.

In all discussions on model design and testing, the importance of the time factor has been considered. The technical conclusions reached in this meeting are aimed not only at a fair and exact efficiency comparison, but also to find practicable solutions to realize this purpose under a pressing time schedule.

6. PROTOTYPE DATA

DMJM confirms that the hydraulic data and requirements for the prototype as given in the DWR draft specification are valid and shall be used for the design of prototype and model. Materials and mechanical details of the specification are subject to later modifications.

DMJM also confirms that allowable working stresses (1/3 yield, 1/5 ultimate) shall be calculated for shut-off head (2600 feet) not for the test pressure (1500 psi). The calculated stresses applying to this rule are the "main" stresses in the element, not the "combined" stresses. The ASME Paper No. 62-WA 166 shall not apply.

7. PROTOTYPE DESIGN

Each bidder shall design the prototype pump. The design shall be detailed to such an extent that all parts influencing the hydraulical and mechanical performance are final. Working drawings are, of course, not required. Stress calculations shall be made for all major parts and especially for those where mechanical strength influences the hydraulic shape. The shaft critical speed shall be calculated for the pump shaft alone (neglecting the rigid coupling with the motor and assuming rigid bearings) and shall be not less than 1040 rpm (600 x 1.33 x 1.30). All three manufacturers recommend not to split the balancing labyrinth. The specification must be changed accordingly.

8. MODEL DESIGN

It is recognized that the design details as discussed and agreed upon in this meeting shall ensure comparability of test results to the best possible extent, while on the other hand giving as much freedom as possible to the designer to realize the design he considers to be the best.

It is also realized that the conclusions reached on the model design must be final and that any modification would severely influence the time schedule.

8.1 Model Size

The model size shall be defined as the outside diameter of the impellers, measured across the outlet edges of the blades. If the four impellers have different diameters, the arithmetic mean of the four impeller diameters shall be the model size.

The model size shall be between 15.0 - 15.5 inches. These limits would allow a variation in model size of 3.7 %. The final model ratio for purposes of evaluation will be determined after completion of the comparative tests at NEL. This model ratio will be used to determine the evaluated prototype efficiency.

8.2 Clearances and Leakage Losses

It is recognized that true similarity between model and prototype cannot be maintained for the wear ring and balancing labyrinth clearances. The high value of the efficiency may lead designers to use extremely small clearances on the model which would sacrifice the safe operation of the model. To avoid this risk and to maintain comparability of the models, it is mutually agreed that the mean clearance of all wear rings and balancing labyrinth shall not be less than 0.4 mm in diameter, and that no individual clearance shall be less than 0.35 mm in diameter. This clearance shall be checked by the Engineer before the model is assembled.

The shape and throttling lengths of the wear rings and the balancing labyrinth shall be homologous with the prototype design.

For the efficiency tests the pump shall be operated with a suction pressure corresponding to plant sigma. The balancing chamber shall be connected to the suction with a pipe large enough to maintain a pressure in the balancing chamber not exceeding 110 % suction pressure. It is agreed that under these conditions no correction for balancing leakage losses shall be applied in calculating the model efficiency.

8.3 Model Bearings and Shaft Seals

The models shall be equipped with ball bearings. All models shall use the same make, type, size, catalogue number, and clearance class bearings, which shall be determined jointly by the bidders in the design process.

The models shall be equipped with labyrinth type seals.

It is reasonable to assume that under these conditions any differences in bearing and shaft seal losses between the models will be negligible. It is, therefore, agreed that no corrections for bearing losses and other mechanical losses shall be applied in establishing the comparative efficiencies.

8.4 Model Finish

A "polished" surface finish will be required on all hydraulic passages of the model pump. Vane surfaces in the internal passages of impellers and diffusors will be finished to 63 micro-inches CLA (center line average), or better,and the external impeller shroud surfaces and opposing case surfaces will have a surface finish of 125 micro-inches CLA, or better.

8.5 Model Configuration

The model configuration shall be as shown in Fig. 1, to ensure equal set-up and to ease installation at NEL: Horizontal, drive from the volute side, thrust bearing on the volute side, rotation counter-clockwise when looking from the coupling, discharge and suction pipe horizontal on the left side when looking from the coupling.

Mating flanges shall be 10.0 inches NBS on the discharge, in a distance of 750 mm from the pump axis; and 12 inches NBS on the suction in a distance of 900 mm from the axis. Spacer pieces may be used to meet these flange requirements. Flange and bolt dimensions shall be identical for all models. This information is to be provided by NEL.

There will be some differences in model length (distance between inlet and discharge flange), and discharge flange excentricity. These differences shall be adjusted in the NEL piping.

For head measurement the pressure taps will be one diameter from the suction flange and three diameters from the discharge flange. These pressure taps will be provided by NEL.

The shaft coupling design and the design details of pump fixture to the NEL bedplate will be clarified in cooperation with NEL. Each model will be provided with its own bedplate, to match the NEL bedplate. NEL will provide the necessary information.

The suction bend shall be equipped with a minimum of two windows for visual cavitation observation and lighting.

9. TESTING AT BIDDERS LABORATORIES

It is understood that testing under the DMJM "bidder's model" contract is limited to hydraulic and cavitation tests in both bidders and NEL laboratories.

Only the model of the successful bidder, then the "contractor's model", will undergo further testing as outlined in the Prototype Specification, Section 15. This testing will be part of the Prototype Pump Contract. However, all bidders' models shall be designed for later instrumentation for the possible further testing as contractor's model.

The testing will be witnessed by DMJM.

9.1 Hydraulic Tests

The complete hydraulic characteristic shall be measured (H, P, η). At least 12 points shall be measured between 0 and 110 % rated flow, and additional points at approx. 2 % flow interval between 90 % and 110 % rated flow. Additional points shall be taken around any sharp changes in the head or efficiency curves.

These tests shall be made with the complete 4-stage model at a test speed left to the bidder's choice.

Test results shall be converted to a constant speed of 2750 rpm and plotted in relative values Q/Q_o, H/H_o, P/P_o and eta. Rated values Q_o, H_o, shall be derived from the prototype data Q_{op}, H_{op} as follows:

$$\frac{Q_o}{315} = M^3 \; \frac{2750}{600} \; \text{cfs}$$

M = scale factor

$$\frac{H_o}{1970} = M^2 \; {\frac{2750}{600}}^{2} \; \text{feet}$$

Rated values Q_o, H_o, P_o shall be stated on each test sheet.

The hydraulic performance of the model must comply (percentage-wise) with the design conditions and design tolerances given in Section 13 of the Specification, except that the comparative efficiency shall be defined as the best efficiency between 305 and 325 cfs prototype flow.

9.2 Cavitation Tests

The prototype pump setting provides a submergence of 71 feet, giving a NPSH of 103 feet and sigma 0.211 (assuming the first stage develops 1/4 of the total head). These conditions comply with a suction specific speed (gpm basis) of S = 7000.

Model tests must prove that the head and efficiency breakdown does not occur below S = 10 000 and no visible cavitation occurs below S = 6 000 for 315 cfs flow (Specification Section 14). Small bubbles on only one blade are not considered as visible cavitation.

Tests shall be made for approx. 80 %, 90 %, 95 %, 100 %, and 105 % rated flow, for each flow rate from no visible cavitation down to breakdown. The test speed is left to the bidder's choice.

10. NEL TESTING

10.1 General

The testing at NEL has the purpose to establish comparable model efficiencies as a basis for bid evaluation. Since 0.1 % efficiency is evaluated at US-$ 330,000.-- for eleven pumps, all parties concerned are fully aware of the great importance of a true comparison.

All parties concerned have, in one or another way, participated at previous tests at NEL and agree that this laboratory is suitably equipped and its personnel is experienced for such testing; and that, therefore, comparative testing at NEL is considered as a suitable and fair means for bid evaluation.

Bidders agree that such testing, under provisions as in previous tests at NEL, will not involve undue release of proprietory information on their design. DMJM will oblige NEL to take the necessary steps. DMJM itself will, of course, protect the proprietory rights of the bidders and will especially not release any test results before bid opening.

10.2 Test Cost

DMJM will bear, on the behalf of DWR, the cost of the test work at NEL. Each bidder shall, at his cost, provide the necessary boxing for safe shipment of his model, and shall insure his model against damage and loss during shipment and NEL testing. He shall also bear the cost for one mechanic and an authorized test engineer for the NEL testing for the period of one month.

Bidders agree that they are satisfied with these conditions, and that the acceptance of the test result by their representative shall be final. Bidders agree especially that they will not question or criticize test results once they are accepted by their representative, and that they cannot, in any way, raise objection against using these results in bid evaluation.

10.3 Witnessing of Tests

NEL tests will be witnessed by DMJM, and by the bidder's authorized representative. The bidder's representative will have the right to request, in cooperation with DMJM, any reasonable calibration and check on the test equipment to satisfy himself that the test results obtained are correct. He shall sign all test sheets and check the calculations. Within 5 working days after a test series is completed, evaluated and the results handed over to the representative, he shall notify DMJM in writing whether he accepts the test or whether he requests further testing.

10.4 Test Procedure

A complete test series as outlined in chapters 9.1 and 9.2 shall be made at NEL for both hydraulic and cavitation tests. The tests will be run at a test speed of approx. 2750 rpm, which is close to full prototype speed. Test results will again be converted to 2750 rpm. Water temperature shall be maintained within a 5 °C band, equal for all models, for measuring evaluated efficiency test points.

11. PROTOTYPE BIDDING

It is recommended to the DWR as a fair procedure, that DWR shall request price bids for the prototype pumps to be submitted at a time of at least one month before the first model is shipped to NEL; that the price bids are submitted in a sealed envelope, not to be opened before NEL testing is completed. DMJM will then submit to the DWR the comparative efficiency values, again in sealed evelopes, and then the bid opening can take place.

Due to not crediting mechanical and leakage losses, and stipulating minimum wear ring and labyrinth clearances, the absolute level of model efficiencies is somewhat lowered; therefore, the minimum efficiency stepped up to prototype conditions shall be 90.5 %.

12. BID EVALUATION

The comparative model efficiency η' shall be defined as the best point on the model efficiency curve (as defined by the method of least squares) between 305 and 325 cfs prototype flow. To establish this curve, at least 20 test points shall be measured between 295 and 335 cfs prototype flow.

This model efficiency shall be stepped up using the "DMJM" step-up formula

$$\eta = \frac{1}{1 + (1/\eta' - 1) \times M^{0,20}}$$

M = scale factor $\frac{\text{model dia.}}{\text{prototype dia.}}$ (see also Section 8.1)

η = the comparative prototype efficiency to be used in the bid evaluation.

It is recognized that in spite of the greatest effort to obtain results of highest accuracy in the comparative testing, there will be a certain scatter and inaccuracy which cannot be eliminated. It seems, therefore, realistic to allow for these inaccuracies by applying a "dead band". Experience from previous testing at NEL shows that the "dead band" should be ± 0.1 % or 0.2 % (absolute points) total. Efficiencies within this band shall be considered equal, and efficiencies more than 0.2 % below highest value should be evaluated with the difference only, after subtracting the "dead band". The following example illustrates this procedure:

Bidder		A	B	C
Efficiency	%	91.4	91.7	91.9
Absolute difference	%	0.5	0.2	0
Evaluated difference	%	0.3	0	0

It is the opinion of all parties present at this meeting that this procedure will ensure a fair and reasonable bid evaluation considering both the high value of the efficiency and the unavoidable inaccuracies in measuring it.

13. STATEMENT OF AGREEMENT

This record was drafted during the meeting. Each party will receive 5 copies of the final record and shall return 3 signed copies to DMJM by June 20, 1966, hereby declaring that the statements in this record conform with the points discussed and agreed upon in the meeting, and that they will accept a comparative model test contract from DMJM which in its technical contents is based on the decisions reached in this meeting, provided agreement is also reached on commercial and legal items. It is understood that DMJM will submit this record to the DWR and ask for their approval.

Encl.: Fig. 1

Daniel, Mann, Johnson
& Mendenhall

Hans Gartmann

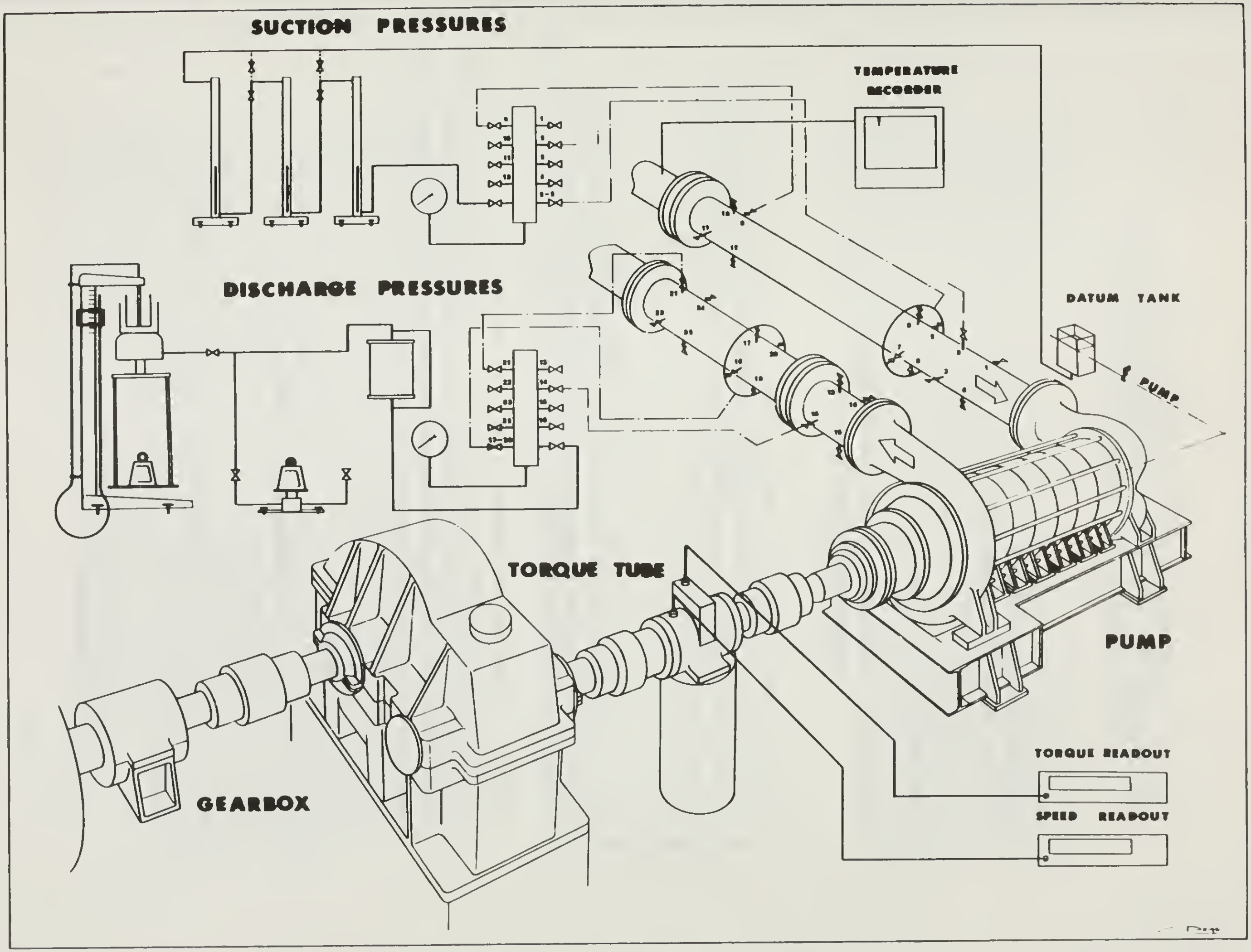
Motor-Columbus
Electrical Management
Company Ltd.

Hartmann

Baden, June 8, 1966

We hereby declare that our representatives present at the meeting agreed on our behalf to the statements contained in this record.

Date: Firm:



TEST INSTRUMENTATION

"LETTER OF INTENT"

29 June 1966

Allis-Chalmers
Baldwin-Lima-Hamilton
Newport News Shipbuilding & Drydock Co.

Gentlemen:

Reference: Tehachapi Model Test Contract
Specification No. 637-1-2
Letter of Intent

With our letter of June 29, 1966 you have received the form Contract Agreement and Specification 637-1-2 stating the requirements for building and testing a 4-stage pump model. These documents reflect the engineering decisions arrived at in a joint meeting held at Baden, Switzerland on June 7, 1966.

300 FOR B-7-4

In your telegram dated June 16, 1966 you have agreed to a price for this work of $130,000.00 and have also specified an elapsed time of 335 calendar days for completing the work including delivery of the model to the National Engineering Laboratory at East Kilbride, Scotland.

Pending completion and signing of the Contract Agreement by both parties and the approval of the Department of Water Resources, DMJM is hereby authorizing you to proceed with the work on the Contract effective July 1, 1966 in accordance with all terms and conditions thereof. Specifically, this authorization is subject to the Termination Clause as set forth in Article 12 of the Contract Agreement.

Very truly yours,

DANIEL, MANN, JOHNSON, & MENDENHALL

I. F. Mendenhall
President

cc: Allis-Chalmers, Los Angeles
Motor-Columbus (2)

IFM/mjp

ABSTRACT FROM COVER LETTER TRANSMITTING MODEL CONTRACT DOCUMENTS DEALING WITH EVALUATION PROCESS

/ On evaluating the bids/. . . . . the model efficiency will be considered whereby a minimum "stepped up" model efficiency of 90.5% must be achieved. The measuring capability of the Independent Laboratory will be assumed accurate and accepted as binding because it will be used for all competitive models. The same rules for handling laboratory data will be applied to all models. The best efficiency point of the model will be rounded off to the nearest 0.1% with .05 being rounded to the next higher tenth percent.[1] The model efficiency will be "stepped up" to the prototype efficiency using the formula:

$$\eta = \frac{1}{1 + \left(\frac{1}{\eta'} - 1\right) (D'/D)^{.20}}$$

η = Prototype Efficiency

η' = Model Efficiency

D'/D = Scale ratio, model impeller diameter to prototype impeller diameter

Again, the calculated number will be rounded off to 0.1% with .05% rounded to the next higher tenth. Having calculated the prototype efficiency by "stepping up" the model efficiency, the prototype bids will be evaluated in the following manner: The difference between the model with the highest efficiency and the efficiency of another model will be determined; a "dead band" value of 0.2% will be subtracted from the difference; and the net value will be multiplied by $30,000 per pump ($330,000 for 11 pumps).[2] This figure will then be added to the prototype bid price of the manufacturer of this other model and will then constitute the bid evaluation figure. The lowest bid evaluation figure will determine the award of the contract for the

1 In the final procedure, the model efficiency was not rounded off but instead 2 decimal place model results were used with a computer calculation for obtaining the "stepped up" efficiency value that was then rounded off to the nearest 0.1%.

2 Later changed by the Department to 22,000 per pump and to 7 pumps for the procurement quantity.

prototype pumps. The amount of the award will be the actual bid figure. To clarify this process, the following example is provided:

Manufacturers are X, Y, and Z bidding on 11 pumps.[2]

Manufacturer	X	Y	Z
Model efficiency ("stepped up" to prototype value)	91.8	91.5	91.3
Difference from highest	0	.3	.5
Adjustment for .2% "dead band"	0	.1	.3
Bid penalty figure	0	$330,000	$990,000
Prototype bid (award amount)	$X	$Y	$Z
Bid evaluation figure	$X	$Y+330,000	$Z+990,000

END OF ABSTRACT

CONTRACT AGREEMENT

THIS AGREEMENT made the ________ day of ____________________ in the year ________ by and between ______________________________________ ____ hereinafter called the Contractor, and DANIEL, MANN, JOHNSON, & MENDENHALL, a California corporation having its principal place of business at 3325 Wilshire Boulevard, Los Angeles, hereinafter called the Engineer,

WITNESSETH:

WHEREAS, the Engineer has entered into an Agreement with the Resources Agency of California, Department of Water Resources, hereinafter called the Department for certain services in connection with the design of the pumps for the California aqueduct project; and

WHEREAS, the Engineer desires to obtain certain services from the Contractor in connection with the development of pumping equipment for said aqueduct project; and

NOW, THEREFORE, the Engineer and Contractor for considerations hereinafter set forth agree as follows:

Article 1. Statement of Work.

The Contractor agrees to furnish all labor, materials and equipment and perform all work necessary to complete the design, fabrication and testing of a four-stage pump model, in strict conformance with the Engineer's specification entitled Specification for the Design, Fabrication and Testing of a 4-Stage Pump Model for Tehachapi Pumping Plant, California, Specification Number 637-1-2, hereinafter called Specification. By this reference the Specification is incorporated herein and made a part hereof and shall be as fully a part of the Contract as if herein repeated. The work to be performed by the Contractor shall, generally, be as follows:

A. Basic Design of a Prototype Pump

Preparation of the basic design of a prototype of the four-stage pump. Such design shall include but not be limited to the layout outline and cross-section drawings indicating the overall dimensions of the full size pump and the general arrangement of the basic elements of the pump and the design calculations and data giving basic stresses for the major pump parts and the shaft critical speed (pump rotating elements only not including the motor).

B. Design of Model Pump

Preparation of the design of a Model Pump, hereinafter called Model, homologous with the prototype design prepared pursuant to Paragraph A next above (except for seal clearances) with an impeller diameter of not less than fifteen (15) inches and not more than fifteen and one-half ($15\frac{1}{2}$) inches and meeting certain overall dimensional requirements and flange sizes set forth in the Specification. The model design documents shall include but not be limited to detailed assembly and installation drawing clearly indicating lubrication connections, instrumentation locations and all other information and details necessary for the assembly, installation and operation on the Model.

C. Prototype and Model Pump Design Report

Preparation of a report describing the Prototype and Model designs in detail and including all drawings, calculations and other data prepared pursuant to Paragraphs A and B of this Article 1., subject to the provisions of Article 5. Ownership. Such report shall be submitted to the Engineer in one (1) reproducible autopositive vellum copy and twenty-five (25) copies.

D. Model Fabrication and Contractor Testing

1. The Contractor will fabricate the Model, conduct preliminary tests for H (Head), Q (Flow rate), efficiency and cavitation, utilizing his own facilities at model operating speeds determined by him, design and fabricate additional pump components and conduct retests as necessary to achieve the optimum H, Q, efficiency and cavitation test results.

2. Upon completing the work required by Paragraph 1 above, the Contractor will do all things necessary to deliver the Model along with all necessary accessory or auxiliary equipment to an independent laboratory to be designated by the Engineer.

E. Independent Laboratory Test

1. Supervision of the Model installation at the independent laboratory to assure that the installation is proper and conforms to the functional requirements of the Model.

2. Provide a Technical Representative at the independent laboratory to provide consulting services to the Engineer and laboratory personnel as required to answer any questions concerning operations and test procedures during the testing.

3. Supervise dismantling of the Model and doing all things necessary to return the Model to the Contractor's plant.

F. Test Report

Preparation of a report covering in detail the H, Q, efficiency and cavitation tests results for the preliminary tests on all components tested at the Contractor's facility and a comparative analysis of these with those conducted at the independent laboratory. Twenty-five (25) copies of this report shall be submitted to the Engineer for approval plus one (1) reproducible copy (original or autopositive vellum).

G. Monthly Progress Reports

Preparation of a monthly progress report describing in detail the work accomplished the preceding 30 days, any problems encountered and indicating the percentage of completion of each item of work under this Contract. This report shall be submitted in ten (10) copies on the 15th day of each month during the term hereof.

Since the Model will be and remain the sole property of the Contractor, it is understood and agreed that in the event the Model, or any accessory or auxiliary equipment thereto, is in any manner damaged, lost or destroyed due to whatever cause, all costs and expenses of any repairs or replacement shall be borne by the Contractor.

Article 2. Time of Completion.

It is expressly understood and agreed that time is of the essence of this Contract. The Contractor shall commence the work to be performed under this Contract on the date stipulated in the Engineer's written notice to proceed and the Contractor shall thereafter complete the work required in Article 1. hereof through and including Paragraph D, no later than ________ calendar days from the date of said notice to proceed, subject to an increase or decrease in the time for completion pursuant to Article 8 hereof, entitled "Extra, Additional or Omitted Work."

Article 3. Contractor's Compensation.

A. In consideration of the Contractor's satisfactory performance of the work as required hereinabove, the Engineer agrees to compensate the Contractor a Fixed Price amount of ONE HUNDRED THIRTY THOUSAND DOLLARS ($130,000.00). The Engineer shall make progress payments on account of said Fixed Price as follows:

		% of Fixed Price Payable
1.	Upon completion of the Basic Design of a Prototype Pump, Design of Model Pump and Prototype and the Prototype and Model Pump Design Report and acceptance thereof by the Engineer	30%
2.	Upon completion of Model Fabrication and Contractor testing, and the arrival of the Model at the independent laboratory	30%
3.	Upon completion of all testing of Contractor's Model at the independent Laboratory	20%
4.	Upon submittal of the Test Report	10%
5.	Upon Engineer's approval of the Test Report	10%
	TOTAL	100%

B. The making of any payment to the Contractor under this Contract shall not relieve the Contractor of his obligations to complete each item of work set forth in the Statement of Work in its entirety, and to deliver to the Engineer such reports and other information required by the Contract, and until this Contract is fully performed by the Contractor and the work required thereby is accepted by the Engineer, the Contractor shall, without additional compensation, retest, redesign, repair, replace, restore or rebuild any fully or partially completed work, or any materials or equipment required to be provided under the Contract as may be directed by the Engineer.

Article 4. Examination of the Work.

The Engineer or the Department shall have the right to observe the Contractor's performance of the work hereunder at any time or times prior to the submittal of the Test Report.

Article 5. Ownership.

A. The Contractor shall deliver to the Engineer, at the time the Contractor submits the Test Report, one (1) reproducible (original or autopositive vellum) and two (2) copies of all original drawings, processed data, and other information developed in connection with the work hereunder. All items so delivered shall become the property of the Engineer. It shall be understood that the term "drawings" applying to the Model and to the prototype shall mean detailed assembly drawings which include major dimensions of parts, the wearing clearances between rotating and stationary parts, plus arrangement drawings showing the overall dimensions required for making installation layouts and other detail drawings which may be required for the testing program. Proprietary items consisting of design details of the hydraulic passages of the impellers, the diffusers and the pump casings shall not be delivered to the Engineer.

B. Drawings, design data, test results, reports or any other information pertaining to the services under this Contract shall not be transmitted to others than the Engineer or Department, including the press, without the express written permission of the Department.

Article 6. Subcontracts.

A. Subcontract. The term subcontract as used herein includes any agreement with a third party for providing or procuring services, materials or equipment pursuant to the work required by the Contract, except purchase orders, the total value of which is less than $10,000 shall not be considered a subcontract.

B. It is understood and agreed by the parties hereto that the Contractor shall subcontract with or otherwise retain the services of

____

____

to perform major portions of the work required by Article 1. hereof in association with the Contractor.

C. Except as provided in Paragraph B next above, the Contractor shall not subcontract any work to be performed or any materials to be furnished in the performance of this Contract without the prior written consent of the Engineer. If the Contractor shall subcontract any part of this Contract, the Contractor shall be as fully responsible to the Engineer for the acts and omissions of his subcontractor and of the persons either directly or indirectly employed by the subcontractor to the same extent as he is for the acts and omissions of persons directly employed by the Contractor. Nothing contained in this Contract shall create any contractual relation between any subcontractor and the Engineer.

D. The Engineer's consent to or approval of any subcontract under this Contract shall not in any way relieve the Contractor of his obligations under this Contract and no such consent or approval shall be deemed to waive any provision of this Contract.

E. The Contractor shall include in any subcontract let, "termination for convenience" provisions, authorizing termination by him on the same terms and conditions as set forth in Article 12 hereof.

Article 7. Permits - Compliance with Law.

The Contractor shall obtain all permits, and licenses and pay all taxes necessary for the performance of this Contract, without additional expense to the Engineer (except any California state and local sales and use taxes or Federal import duty taxes), and give all necessary notices, pay all fees required by law, and comply with all laws, ordinances, rules and regulations governing the Contractor's performance of the Contract.

Article 8. Extra, Additional or Omitted Work.

A. The Engineer may by written order require changes in this Contract, or additions to or deductions from the work to be performed, or in the time schedule for performance of any work. Upon receipt of such written order requiring a change, the Contractor will immediately proceed with the performance of the Contract as changed. In the event any such change causes an increase or decrease in the cost of performance, or in the time required for performance of the Contract, or both, an equitable adjustment shall be made in an amount mutually agreed upon and the Contract shall be modified in writing accordingly.

B. Any claim for adjustment under this clause shall be deemed to be waived by the Contractor unless asserted within fifteen (15) days from the date of the Contractor's receipt of the Engineer's order requiring the change. Any claim for adjustment must set forth the amount of any proposed increase or decrease in the cost of performance, or in the time required for performance or both and the Engineer may require any additional data or information he deems necessary for evaluation of the claim.

Article 9. Reports and Other Submittals.

A. Preparation and Transmittal

1. All reports, charts and other data to be submitted to the Engineer must be prepared in the English language. The Test Report required by Article 1 hereof must use the English system of dimensioning for drawings and the English system of measurements for pressures, flow rates, specific speeds and horsepowers.

2. Interim reports of individual test readings using metric measurements will be accepted. All documents, data, letters, reports and other information or material requiring the Engineer's action and the Engineer's reply thereto shall be made by air mail service.

B. Review and Approval

1. Interim Report and Progress Submittals: It shall be understood and agreed that the Contractor shall continue the performance of the work pending approval of any and all reports and progress submittals as required by the Statement of Work and that the time for such approval shall not be excepted from the time for completion.

Article 10. Patent Rights.

As used in this clause, the following terms shall have the meanings set forth below:

A. Definition

The Term "Subject Invention" means any invention, improvement, or discovery (whether or not patentable) conceived or actually reduced to practice by the Contractor, Subcontractor, or any employees thereof, in the performance of the experimental, developmental, research or any other work called for or required under this Contract.

B. Subject Inventions

1. The Contractor agrees to and does hereby grant to the Department an irrevocable, non-exclusive and royalty-free license to practice, and cause to be practiced by or for the State of California throughout the world, each Subject Invention. Such license shall be non-transferable and shall include the practice of Subject Invention in the manufacture, use, and disposition of any Subject Invention or for the Department.

2. The obligation of the Contractor to grant a license as provided in B.1 above, shall be limited to the extent of the Contractor's right to grant the same without incurring any obligation to pay royalties or other compensation to others solely on account of said grant. Nothing contained in this Patent Rights clause shall be deemed to grant any license under any invention other than a Subject Invention.

3. The Contractor shall, unless otherwise authorized by the Engineer, include a patent rights clause containing all the provisions of this Patent Rights clause in any subcontract hereunder having experimental, developmental or research work as one of its purposes. In the event of refusal by a subcontractor to accept such a patent rights clause, the Contractor shall promptly submit a written report to the Engineer setting forth the subcontractor's reasons for such refusal and other pertinent information which may expedite disposition of the matter, and shall not proceed with the subcontract without the written authorization of the Engineer.

4. It is understood that with respect to any subcontract clause granting rights to the Department in Subject Inventions, the Department is a third party beneficiary; and the Contractor hereby assigns to the Department all the rights that the Contractor would have to enforce the subcontractor's obligations for the benefit of the Department with respect to Subject Inventions.

Article 11. Interpretation of Contract Documents.

It is understood that this is a California agreement, and shall be governed by the laws of the State of California, both as to interpretation and performance. Any and all suits for any and every breach of this agreement shall be instituted and maintained only in courts of competent jurisdiction in the State of California.

Article 12. Specifications.

A. Interpretation: Should it appear that the work to be done or any of the matters relative thereto are not sufficiently detailed or explained in the specifications, the Contractor shall apply to the Engineer for such further explanations as may be necessary and shall conform thereto as part of the Contract.

B. Errors and Discrepancies: Prior to execution of the work, the Contractor shall check all specifications, and shall immediately report all errors, discrepancies, and omissions discovered therein to the Engineer. All such errors, discrepancies and omissions will be adjusted by the Engineer. Any adjustments made by the Contractor, without prior approval, shall be at his own risk.

Article 12. Termination.

A. Notice of Termination for Default or Convenience: The Engineer may at any time terminate performance of the work under this Contract in whole or in part for the default of the Contractor, or in whole or from time to time in part for the convenience of the Engineer or Department, by written notice to the Contractor stating the ground for termination. Such termination shall be effective in the manner and upon the date specified in said notice and shall be without prejudice to any claims which the Engineer may have against the Contractor.

B. Liability for Default: Nothing contained in this Article shall be construed to limit or affect any remedies which the Engineer may have as a result of a default by the Contractor.

C. Termination for Default: The performance of the whole or any part of the work may be terminated for default if the Contractor refuses or fails to prosecute the work or otherwise fails or refuses to fulfill any obligation under the terms of the Contract with such diligence as will insure its completion within the time for completion stated in the Contract.

1. In the event the Engineer terminates this Contract in whole or in part as provided in paragraph C. next above, the Engineer may procure, upon such terms and in such manner as the Engineer may deem appropriate, supplies or services similar to those so terminated, and the Contractor shall be liable to the Engineer for any excess costs of such similar supplies or services. The Contractor shall continue the performance of this Contract to the extent not terminated under the provisions of this clause.

D. Termination for Convenience:

1. After receipt of a Notice of Termination, and except as otherwise directed by the Engineer, the Contractor shall:

   a. stop work under the Contract on the date and to the extent specified in the Notice of Termination;

   b. place no further orders or subcontracts for materials, services or facilities, except as may be necessary for completion of such portion of the work under the Contract as is not terminated;

   c. terminate all orders and subcontracts to the extent that they relate to the performance of work terminated by the Notice of Termination;

   d. assign to the Engineer, in the manner, at the times, and to the extent directed by the Engineer, all of the right, title and interest of the Contractor under the orders and subcontracts so terminated, in which case the Engineer shall have the right, in his discretion, to settle or pay any or all claims arising out of the termination of such orders and subcontracts;

   e. settle all outstanding liabilities and all claims arising out of such termination of orders and subcontracts, with the approval or ratification of the Engineer, to the extent he may require, which approval or ratification shall be final for all the purposes of this Article;

   f. deliver to the Engineer, in the manner, at the times, and to the extent, if any, directed by the Engineer, the completed or partially completed plans, drawings, information, and other property which, if the contract had been completed, would have been required to be furnished to the Engineer;

   g. complete performance of such part of the work as shall not have been terminated by the Notice of Termination; and

h. take such action as may be necessary, or as the Engineer may direct, for the protection and preservation of the property related to this Contract which is in the possession of the Contractor and in which the Engineer has or may acquire an interest.

2. After receipt of a Notice of Termination, the Contractor shall submit to the Engineer its termination claim, in the form and with certification prescribed by the Engineer. Such claim shall be submitted promptly but in no event later than six months from the effective date of termination, unless one or more extensions in writing are granted by the Engineer, upon request of the Contractor made in writing such six-month period or authorized extension thereof. Upon failure of the Contractor to submit its termination claim within the time allowed, the Engineer may determine, on the basis of information available to him, the amount, if any, due to the Contractor by reason of the termination and shall thereunder pay to the Contractor the amount so determined.

3. Subject to the provisions of paragraph 2. next above, the Contractor and the Engineer shall agree upon the whole or any part of the amount or amounts to be paid to the Contractor by reason of the total or partial termination of work pursuant to this Article, which amount or amounts shall include a reasonable allowance for profit on work done; provided that such agreed amount or amounts, exclusive of settlement costs, shall not exceed the total contract price as reduced by the contract price of work not terminated. The Contract shall be amended accordingly, and the Contractor shall be paid the agreed amount.

E. Accounting Records of the Contractor: The accounts and records of the Contractor's direct personnel and other direct costs pertaining to the work hereunder shall be kept on a generally recognized accounting basis. It is understood and agreed that only in the event this Contract is terminated in whole or in part, such accounts and records shall be available to the Engineer or his authorized representative for inspection at mutually convenient times.

Article 13. Indemnification.

The Contractor agrees to and shall hold and save the Engineer and Department, their officers, agents, representatives and employees harmless from any liability for damages or claims for damages resulting or alleged to have resulted from personal injury, including death, as well as from liability or claims for property damage, which may arise from the Contractor's act or omissions under this Contract, whether such costs or omissions be by the Contractor or any one or more retained by, employed by or acting as agent for the Contractor.

Article 14. Successors and Assigns.

The Contractor shall not assign, or transfer his interest in this Agreement without the express written consent of the Engineer.

The Engineer and the Contractor each binds himself, his successors and assigns of such other party in respect of all covenants of this Agreement.

Article 15. Agreement Subject to Approval.

It shall be understood by both the Engineer and the Contractor that this Agreement is subject to the approval of the Department and shall not be binding on either party until the Department has given its express approval in writing to the Engineer. The Engineer shall notify the Contractor of the Department's approval by transmitting to the Contractor a copy of the approved document received by the Engineer from the Department.

IN WITNESS WHEREOF the parties hereto have executed this Agreement, the day and year first above written.

Contractor

(Seal)

By ______________________________

Title ______________________________

Engineer
DANIEL, MANN, JOHNSON, & MENDENHALL

(Seal)

By ______________________________

Title ______________________________

DMJM

DANIEL, MANN, JOHNSON, & MENDENHALL

August 19, 1966

PRESIDENT
IRVAN F. MENDENHALL, C.E
EXECUTIVE VICE PRESIDENTS
PHILLIP J. DANIEL, A.I.A
ARTHUR E. MANN, A.I.A
S. KENNETH JOHNSON, A.I.A
STANLEY A. MOE, A.I.A
T. K. KUTAY, A.I.A

Subject: Tehachapi Pumping Plant
DMJM Model Specification 637-1-2
Changes and Corrections

Gentlemen:

Enclosed are nine (9) copies of Amendment No. I to DMJM Contract Agreement 637-1-2 incorporating DMJM Specification 637-1-2 for model pumps and the Preliminary Technical Provisions of the Tehachapi prototype pump specification.

You will note that although we are allowing more time for submission of the Design report, the time for delivery of the model to the Independent Laboratory is still firm and completion of design work as soon as possible is highly recommended.

It has been suggested that 15 days is not an adequate time for submitting the final test report (page 2, second paragraph of Specification 637-1-2). In this connection, your attention is directed to the following comments:

(1) The Contractor will have at least 30 days from the time his model is delivered to the Independent Laboratory until the official tests are complete in which to prepare results of his preliminary testing.

(2) Completion of official tests (first line of referenced paragraph) will mean the time the last of the test data is given to the Contractor and accepted by the Contractor.

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(3) The comparison and analysis between preliminary Contractor tests and the official tests of the Independent Laboratory shall be short and simple with the main purpose being the choosing of the ratio D'/D and the consequent performance limits and efficiency value to be used in the prototype bid evaluation. The Contractors do have the freedom of selecting the D'/D ratio after the official tests. A critique of the Independent Laboratory results is not desired or expected. The Contractors have agreed as evidenced by the June, 1966 Baden Agreement to accept the results of the Independent Laboratory as final and binding. As a consequence of this consideration, Amendment item number 9, is being added to the model specification.

(4) Because these results will be used in the bid evaluation, they will be needed very soon after the last model test. To be fair, a uniform rule will be applied to all Contractors without regard for which model shall be last in the schedule.

(5) No extension in time can be granted for submitting the test report.

Regarding the prototype technical provision, there are proposed changes that all Contractors should know of now. The details of Section 12 will probably be revised for clarification. One specific and important change will be to allow Class 3 castings with a pilot casting rather than require Class 2 castings (see last paragraph page 12-2).

In Section 12, Article (b) and Section 15, Article (b), paragraph (4), due to the nature of the hydraulic design of the stay vanes in the discharge spiral and the difficulty of determining stresses accurately, a special stress calculating method and allowable stress will probably be added to the specification. The details have not been resolved; however, the calculated stresses will probably be permitted to exceed the 1/3 yield or 1/5 ultimate limit imposed on all other parts of the pump. Details of this specification change will be sent out as soon as they are finalized.

We have endeavored to incorporate changes in the Contract Agreement as requested by the Contractors. Due to certain State procurement policies, we are unable to make all of the changes requested.

We will appreciate receiving by return mail seven (7) properly executed copies of the Agreement and Amendment 1. After DMJM's execution and approval of the Agreement and Amendment by the State, we will return two (2) fully executed copies to you.

Very truly yours,

DANIEL, MANN, JOHNSON, & MENDENHALL

Ray D. Bowerman RB

Ray D. Bowerman
Project Engineer
/sk

Enclosure

AMENDMENT NO. 1

TO

AGREEMENT BETWEEN

____

AND

DANIEL, MANN, JOHNSON, & MENDENHALL

THIS AMENDMENT, entered into this ______ day of ____________,

1966, by and between ____,

located at ____;
hereinafter called the Contractor, and DANIEL, MANN, JOHNSON, & MENDENHALL, a California corporation, having its principal place of business at 3325 Wilshire Boulevard, Los Angeles, California; hereinafter called the Engineer;

W I T N E S S E T H

WHEREAS, the Contractor and the Engineer have entered into an Agreement dated __________________________; hereinafter called the Agreement, for the development of pumping equipment for the California aqueduct project, and

WHEREAS, the Contractor and Engineer desire to amend the Agreement.

NOW, THEREFORE, the Contractor and the Engineer agree to hereby amend the Agreement as follows:

A. CONTRACT AGREEMENT

1. Article 1. - Statement of Work of the Contract Agreement is amended by inserting the word "preliminary" between the words "and" and "Test-" as they appear in the second line of the first paragraph thereof.

2. Article 1. - Statement of Work, Paragraph D. Model Fabrication and Contractor Testing, Subparagraph 2. thereof, is amended by adding the following sentence:

   "The term 'Independent Laboratory' as used throughout this Contract Agreement and Specification Number

637-1-2 shall be understood to mean the National Engineering Laboratory, Fluid Mechanics Division, East Kilbride, Glasgow, Scotland, unless the Engineer otherwise directs under the provisions of Article 8. hereof."

3. Article 2. - Time of Completion of the Contract Agreement is amended by inserting the following sentence at the end of said Article 2:

   "It is understood and agreed by the Contractor that in the event he fails to complete the work under this contract within the time herein set forth, the Contractor may be disqualified for bidding on the prototype pumps as determined by the Department in its sole discretion."

4. Article 7. - Permits - Compliance with Law of the Contract Agreement is hereby amended by inserting the following sentence at the end of said Article 2:

   "In the event that California State and local taxes or Use Taxes or Federal Import Taxes are paid by the Contractor for performance of this Contract, the actual cost thereof will be billed to the Engineer as a separate item and paid by him in addition to the compensation due the Contractor pursuant to Article 3. hereof."

5. The number of Article 12 - Specifications - as it appears in the Contract Agreement, Page 8, is hereby changed to "Article 11-1 Specifications."

6. Article 13 - Indemnification of the Contract Agreement is amended by deleting the word "cost" as it occurs in the sixth line and inserting the word "acts" in place thereof.

B. MODEL SPECIFICATION NUMBER 637-1-2

1. Article (a) General of Specification Number 637-1-2 is amended by changing the number of days for the Contractor's submittal of the design report from "60" to "90".

2. Article (a) General of Specification Number 637-1-2, the second paragraph thereof, is amended by inserting the following sentence in the eighth line of the paragraph between the words "rate" and "The".

   "The model will be operated down to a flow rate of 10% of design flow rate and at lower low rates near shut-off for time periods designated by the Contractor such that overheating of the Model will not occur."

3. Article (a) General of Specification Number 637-1-2, the fifth paragraph thereof is amended by inserting the following sentence at the end of said paragraph:

> "With the acceptance of the test results by the Contractor's Representative, the Contractor agrees to waive any right to contest such results in any manner whatsoever. The Engineer may require additional tests at any time prior to the award of a contract for the prototype pumps at his sole discretion."

4. Article (b) Model Performance - Table I Prototype and Model Performance Criteria of Specification Number 637-1-2 in the bottom section thereof, insert the following sentence:

> "In calculating S, Q is expressed in gallons perminute (gpm), N in revolutions per minute (RPM), and NPSH in feet."

5. Article (b) Model Performance, Paragraph (2) Model H, Q, and Efficiency, Subparagraph a. of Specification Number 637-1-2 is amended by inserting the word "nominal" after the term "2750 RPM."

6. Article (c) Model Design and Construction, Paragraph (1) Clearances of Specification Number 637-1-2 is amended by deleting the number 0.16 in the second line, and inserting the number 0.016 in place thereof.

7. Article (c) Model Design and Construction, Paragraph (4) Model Configuration of Specification Number 637-1-2 is amended by changing the number of days for the Contractor to supply the Model dimensions from "60" to "90".

8. Article (c) Model Design and Construction, Paragraph (8) Design Report of Specification Number 637-1-2 is amended by deleting the number "60" and inserting in place thereof the number "90".

9. Article (d) Model Tests and Procedures, Paragraph (2) Official Tests, Subparagraph a. Head, Flow Rate, Efficiency is amended by inserting the following sentence after the listing of suction conditions:

> "The model will be operated at a submergence equivalent to the above conditions with a tolerance of -0 feet, + 2 feet."

Except as expressly amended or modified hereby, all terms and conditions of the Agreement remain in full force and effect.

IN WITNESS WHEREOF, the Contractor and Engineer have executed this amendment on the day and year first above written.

CONTRACTOR

(Seal) By ______________________________

Title ______________________________

ENGINEER
DANIEL, MANN, JOHNSON, & MENDENHALL

(Seal) By ______________________________

Title ______________________________

SPECIFICATION FOR THE DESIGN, FABRICATION AND TESTING OF A 4-STAGE PUMP MODEL FOR TEHACHAPI PUMPING PLANT, CALIFORNIA SPECIFICATION NUMBER 637-1-2

Article (a) General. -- Immediately after receipt of a Notice to Proceed, the Contractor shall proceed with the basic prototype design and the design and construction of the test model. The model shall be entirely new and shall be constructed specifically for the conditions specified herein. Within 60 days after receipt of the Notice to Proceed, the Contractor shall furnish 25 copies of a design report giving details of the prototype and model with calculations and data showing basic compliance with the prototype and model specifications.

The model shall be a complete four-stage model, including suction bend. Each stage shall be homologous with the corresponding stage of the prototype. The model shall have an impeller diameter of 15" to 15.5" (measured across the outlet edges of the blades). Official performance tests shall be performed on the complete model at a speed of 2750 rpm which will produce approximately full prototype head. The model must be mechanically designed for operation at 2750 rpm from 0 flow rate to 120 percent of design flow rate. The model may be designed for conversion to a single-stage (first-stage) pump for cavitation testing if it is thought that the vibration with cavitation breakdown on the full four-stage model will be too difficult to handle. Details of the "cavitation model" will be subject to approval by the Engineer. The model inlet will be equipped with at least two windows (one for light) for observation of cavitation.

Testing for H, Q, efficiency and cavitation will be made to insure compliance with specified rated conditions and for utilizing the efficiency of manufacturer's models in a prototype bid evaluation. The official tests shall be those performed at an Independent Laboratory, unless for reasons of convenience it is decided by the Engineer to test at the manufacturer's facility.

Prior to delivery of the model to the Independent Laboratory, the Contractor shall perform such preliminary tests in his own laboratory as he sees fit in order to satisfy himself that the model performance is correct. The Contractor shall not submit the results of preliminary tests to a person, firm, agency or other party including the Engineer until the conclusion of the official tests of his model.

The Contractor will ship the model to the Independent Laboratory and will provide supervision of the erection and operation of his model at the laboratory. Return shipment of the model to the Contractor's facility will be the responsibility of the Contractor. The Independent Laboratory tests will be witnessed by the Engineer, the Department, and by the Contractor's authorized representative. The Contractor's representative will have the right to request any reasonable calibration or check on the test equipment to satisfy himself that the test results obtained are correct in accordance with Article (d), Section (2), paragraph c, hereof. He shall sign all test sheets and check the calculations. Within five (5) working days after a test series is completed, evaluated, and the results made available to the Contractor's representative, he shall notify the Engineer in writing whether he accepts the test or whether he requests further testing. Any such requests for further testing must be approved by the Engineer.

Within 15 days of completion of official tests at the Independent Laboratory, the Contractor will prepare a short, final report presenting the results of his preliminary tests on all components and the official tests from the Independent Laboratory with his interpretation thereof and submit 25 copies to the Engineer.

The complete model, including the templates and data required by Article (c), Section (2), shall be available until 180 days after the official testing is complete or, in the case of the Contractor being awarded the prototype contract, until the prototype pumps are all installed and operating satisfactorily at the Tehachapi plant. The Contractor shall be responsible to see that the model shall be preserved carefully and without alteration and shall be the homologue for the prototype pumps.

Article (b) Model Performance. -- The model to prototype scale ratio, D'/D, shall be determined after the official test to permit adjusting the model performance to meet the prototype conditions. The required prototype and model performance design values are listed in Table I.

(1) Performance Limits. -- The limits for the hydraulic performance of the prototype shall be scaled to limits for the hydraulic performance of the model as outlined in Table I. The Contractor will fill in the model data section of Table I -- approximate numbers before the official test based on an estimate of D'/D and exact numbers after official tests based on the finally selected value of D'/D. The approximate model data will be used to guide the official tests with regard to flow settings, etc.

The final selection of D'/D will be such that the prototype performance curve will pass through the values Q = 315 cfs and H = 1970 feet or as close thereto as will allow the maximum efficiency to fall in the range of Q from 305 cfs to 325 cfs.

TABLE I

Prototype and Model
Performance Criteria

Quantity	Prototype	Model (Selected D'/D____)
N	600 rpm	2750 rpm
Q rated	315 cfs	______ [1]
H rated	1970 feet	______ [1]
Q range where rated head must fall	305-325 cfs	______ [1]
Minimum acceptable efficiency in Q range of	90.5% 305-325 cfs	______ [2] ______

The suction specific speed $S = \frac{NQ^{1/2}}{NPSH^{3/4}}$ must be 6000 minimum for observation of cavitation inception and 10,000 minimum for cavitation breakdown (2-percent loss of head or efficiency) at the rated Q for the 2750 rpm test speed.

[1] After selecting the model ratio, D'/D, the model requirements shall be calculated using the affinity laws:

$$H' = \left(\frac{N'}{N}\right)^2 \left(\frac{D'}{D}\right)^2 H \quad \text{and} \quad Q' = \frac{N'}{N} \left(\frac{D'}{D}\right)^3 Q$$

[2] Calculate efficiency from:

$$\eta = \frac{1}{1 + \left(\frac{1}{\eta'} - 1\right)\left(\frac{D'}{D}\right)^{.20}}$$

NOTE:

N = prototype rpm
N' = model rpm
D = prototype impeller diameter
D' = model impeller diameter
H = prototype head
H' = model head

Q = prototype flow rate
Q' = model flow rate
η = prototype efficiency stepped up from model measurement
η' = model efficiency measured in accordance with Section (2) of Article (b) of this specification. The highest value will be used falling in the range given.

(2) Model H, Q, and Efficiency. -- The hydraulic performance of the model shall be measured in accordance with the latest test standards of the Hydraulic Institute Test Code, centrifugal pump section, except as specifically noted in this specification.

a. Test Speed. -- The model shall be tested for head, flow rate, and efficiency at a speed of 2750 rpm.

b. Flow Rate Data Corrections. -- The model flow rate shall be the delivered flow. If the flow rate is measured ahead of the model pump, then shaft and balance labyrinth leakages will be collected and measured and subtracted from the flow rate instrument reading. No correction for shaft seal or balancing labyrinth leakage loss or for model-prototype leakage loss ratio will be permitted. (See Article (d) hereof for test conditions.)

c. Torque Data Correction. -- The model will be subject to a mechanical loss due to the torque required by the thrust bearing. The model will be equipped with ball radial and thrust bearings. The Engineer will specify the bearings by trade name, catalog and type numbers, and class after consulting with all Contractors so that all model Contractors will be using the same bearing types. Identical lubricating systems will be used for all models. The input torque will not be corrected for bearing losses and the bearing losses will have to be accepted as a penalty on the model efficiency.

d. Standard Data Corrections. -- Other corrections as directed by the Hydraulic Institute Test Codes shall be applied. Efficiency shall be computed from measured data at the measured test speed. Head, flow rate, and horsepower data will be corrected to a constant speed of 2750 rpm.

e. Efficiency. -- The official efficiency used for comparative bid evaluation shall be the best point on the model efficiency curve (as defined by the method of least squares) between the flow rates equivalent to the prototype values of 305 and 325 cfs. To establish the curve, at least 20 test points shall be measured between 295 and 335 cfs prototype flow.

(3) Model Cavitation. -- The model will be tested to determine σ and S at the rated flow rate (315 cfs prototype). Values will be determined for the initial observation of cavitation (inception) and cavitation breakdown (defined as a 2% loss of head or efficiency).

The test at 2750 rpm will show that cavitation breakdown does not occur at an S value lower than 10,000 and that no visible cavitation occurs at an S value lower than 6000. Cavitation bubbles on one vane only (local cavitation) will not be considered visible cavitation - more than 1/2 of the blades must show similar starting cavitation to represent the inception point. However, if each blade in turn cavitates while passing through a certain portion of a revolution, this will be considered visible cavitation subject to the S = 6,000 limitation.

Article (c) Model Design and Construction. -- The hydraulic design of the model shall be homologous to the prototype pump. All hydraulic passages and vane shapes including the pump and the suction bend shall be accurately scaled and only seal path clearance shall deviate from model to prototype.

(1) Clearances. -- Clearances on model wear rings and balance labyrinth sealing surfaces will be not less than 0.16 inches (.4 mm) on diameters on the average and the clearance for any single surface shall be not less than .014 inch (.35 mm) on diameter. The clearances will be checked by the Engineer before the model is assembled prior to shipment to the Independent Laboratory.

(2) Model Similarity. -- In order to insure final similarity between the model and prototype pump, the model parts shall be accurately measured for all dimensions, angles, and shapes and any deviations from design drawings noted. These measurements shall be repeated following any modifications resulting from preliminary test work.

The dimensional inspection shall include checking with templates and recording dimensions as follows:

a. Two or more templates of the form of the impeller blades at the inlet.

b. One template of the form of the impeller blades at the exit.

c. Dimensions of the impeller inlet (I. D. of opening and hub O. D.) and the discharge area (distance between shrouds, vane thickness, and O. D.).

d. The throat area of the diffuser.

e. A template of the diffuser blade inlet section.

f. A template of the stay ring vane section.

g. Volute throat and discharge dimensions.

Templates shall be made for all of the four stages if they differ. Dimensional measurements shall be made on all impellers and diffusers used in the model testing. The measurements and templates shall be checked by the Engineer prior to assembly of the components in the Contractor's plant and the data will be signed by the Engineer and retained by the Contractor.

(3) Model Finish. -- A "polished" surface finish shall be provided on all hydraulic passages of the model pump. Vane surfaces and the internal surfaces of the impellers and diffusers shall be finished to 63 microinches CLA (center line average) or better and the external impeller shroud surfaces and opposing case surfaces shall have a surface finish of 125 microinches CLA or better.

(4) Model Configuration. -- The model configuration will be as shown in Figure 1 herein to insure equal set-up and to ease installation at the Independent Laboratory. The model will: be mounted horizontal and be driven from the discharge volute side, have the thrust bearing on the suction end, rotate counter-clockwise when viewed from the drive end, have discharge and suction pipes horizontal and on the left side when viewed from the drive end.

Mating flanges shall be as shown herein in Figure 2 -- 10" for discharge, 12" for suction. The discharge flange shall be 750 mm from the discharge axis (horizontal distance) and the suction flange shall be 900 mm from the axis (horizontal distance). Spacer pieces may be used to meet these distances if the model pump itself is made smaller. The Contractor will furnish such spacer pieces. (All models from all model Contractors will have identical flange and bolt dimensions.)

The model length may vary from one Contractor to the next and the horizontal distance between discharge and inlet pipe centerlines and the eccentric (verticle) distance between the discharge centerline and the pump centerline will be left to the discretion of each Contractor. These dimensions will be supplied to the Engineer within 60 days after Contractor's receipt of Notice to Proceed on the Contract. The Independent Laboratory will adjust the test circuit piping to match these dimensions on each model.

The model will be provided with a bed plate to match the base plate at the Independent Laboratory. The Laboratory base plate will be as shown in Figure 3, with the pump shaft centerline and end located as shown in Figure 3. The model pump shaft end will be 3.0000 - 3.0005 inches diameter for a length of 4 inches with a slot for a 3/4-inch square key as shown in Figure 4.

(5) Bearings.-- The model pump will be equipped with ball bearings for radial loads and axial thrust. All models will be equipped with the same type bearings manufactured by the same manufacturer. The bearings will be specified by the Engineer after consulting with all Contractors. The same lubricating system will be employed for all models and this will also be specified by the Engineer after consulting with all Contractors and the Independent Laboratory.

(6) Cavitation Observation Provisions. -- The suction bend will be equipped with at least two windows for cavitation observation designed to withstand a maximum inlet pressure of 125 psi. The first-stage impeller will have one or more vanes marked by dye spots or other means to permit identifying the vanes and locating their positions when viewed with a stroboscopic light.

(7) Pressure Taps. -- For head measurement, pressure taps will be located one diameter from the suction flange and three diameters from the discharge flange. These pressure taps will be supplied by the Independent Laboratory in the test circuit piping.

(8) Design Report. -- Within 60 days after Contractor's receipt of the Notice to Proceed on the Contract, the Contractor will have completed the design work for the prototype and model and will submit 25 copies of a Design Report to the Engineer, along with one reproducible autopositive vellum copy. The Design Report will include a layout drawing of the prototype pump, an installation drawing of the prototype pump, and calculation for stresses on basic parts and shaft critical speed for the rotating parts of the pump alone. These drawings and data, although of a preliminary nature, shall demonstrate compliance with the prototype specification.

The Design Report shall also include a cross-sectional drawing of the model pump, an installation drawing of the model pump and such other data as will be necessary to conduct the model test program. The number and basic description of all trial components for preliminary testing will be listed.

Article (d) Model Tests and Procedures. -- The models will be subjected to preliminary tests in the Contractor's laboratory for development and checkout and to official testing in the Independent Laboratory. Testing in both laboratories under this Contract will be limited to H, Q, efficiency and cavitation.

Following the official tests for model performance, the prototype bid evaluation and the award of the prototype contract, three quadrant performance tests, axial thrust and radial thrust tests, and pressure fluctuation tests will be performed on the model of the successful prototype bidder under the prototype procurement contract. These tests will be performed at the Contractor's laboratory as outlined in the Prototype Specification (see Technical Provision of the preliminary Prototype Specification included as a supplement to this model specification). The model must be designed to permit performance of these additional tests even though they are not a part of this contract.

(1) Preliminary Tests. -- The preliminary tests will be performed at a test speed and under test conditions chosen by the Contractor. The number and kinds of tests are also at the option of the Contractor, although it should be borne in mind that the official tests at the Independent Laboratory must show compliance with this specification in order for the prototype bid to be accepted and the maximum efficiency that the Contractor can achieve while meeting all other performance conditions will have great bearing on the value of the Contractor's prototype bid. Therefore, the Contractor has incentive to test as many optional components (impeller, diffuser, inlet sections, etc.) as time will allow and to make certain that the chosen components for official testing are optimized in every respect.

The Contractor shall be guided in his preliminary test program by the test procedure and conditions specified for the Official Tests.

(2) Official Tests. -- Official tests will be performed at an Independent Laboratory through contract agreement with the Engineer. The Engineer and the Independent Laboratory will be responsible for conducting official tests and the Contractor's relation will be to provide a representative to assist in erection and operation of the model. The Contractor will have recourse to approve the tests as explained in Article (a).

The Independent Laboratory will perform the tests in the following manner and the Contractor should prepare the model and perform preliminary tests in anticipation of this test program.

a. Head, Flow Rate, Efficiency. -- The testing will be performed at a speed of 2750 rpm. Water temperature will be maintained within a 5°C band -- for all models. For the efficiency tests, the model will be operated with a suction pressure corresponding to plant design conditions. These are:

S = 7000
NPSH = 103 feet
Submergence = 71 feet
Sigma = .21
(assuming the first-stage head equals 1/4 of the total head)

Also, the balancing chamber shall be connected to the suction with a pipe large enough to maintain a pressure in the balancing chamber not exceeding 110% of suction pressure.

Measurements shall be made for a minimum of 12 points in approximately equal increments of flow rate from shutoff to 110 percent of design flow rate. Additional data points shall be taken at approximately 2 percent intervals from 90 percent to 110 percent of rated Q. Also, additional data points shall be taken around any sharp changes in the head or efficiency curves. Points around the design value will be repeated a sufficient number of times, as determined by the Engineer, to insure that any one reading is within the measuring accuracy of the instrumentation and to provide a minimum of 20 test points between the flow rates equivalent to the prototype flow range of 295 to 335 cfs. Points which are more than 0.5% from the tentatively calculated mean curve shall be discarded.

This test data will be used to establish the efficiency curve using the method of least squares. The best efficiency point between the flow rates equivalent to the prototype range of 305 and 325 cfs will be taken for the model efficiency used in the prototype bid evaluation. Establishing the efficiency curve and the best point will be done by the Independent Laboratory and the Engineer.

b. Cavitation Tests. -- Cavitation performance shall be measured by reducing NPSH (suction head) while maintaining a fixed flow rate until a drop in head and efficiency is observed. Readings will always be taken in the direction of reducing NPSH. If flow rate has to be re-established, then NPSH will be raised several feet and brought back down to the desired test value. NPSH shall be reduced until complete breakdown occurs or until a 10-percent drop in head occurs. The starting NPSH shall be sufficiently high such that no visible cavitation is present on the pump impeller. Windows in the pump inlet shall be provided for making visual determinations of cavitation. At least two windows shall be provided to allow for lighting and the taking of photographs. The water temperature will be measured for determining vapor pressure for each cavitation test and will be kept within a band of 5°C for all tests on all models. A sample of water will be drawn and the air content measured at the beginning and end of each cavitation test series to insure reasonable similarity in test conditions for all models.

Cavitation tests as specified above will be performed on the full four-stage model at 2750 rpm at approximately 80 percent, 90 percent, 95 percent, 100 percent and 105 percent of rated Q; or, if the Contractor so desires, he may request that the cavitation tests to be performed on the four-stage model be limited to 2250 rpm without dropping NPSH to breakdown and construct equipment to permit an additional complete test to be performed using only the first stage of the pump at 2750 rpm. The four-stage low-speed results will be compared with the one-stage results to verify that the one-stage model will accurately represent the complete four-stage model. The results shall be reported in the form of curves of head and efficiency vs NPSH. The suction specified speed,

$$S = \frac{N\,Q^{1/2}}{NPSH^{3/4}}$$

shall be calculated for both the point of visible cavitation inception and the breakdown point (2 percent drop in head or efficiency) at 100 percent of rated Q. The model tests must show that at 100 percent Q there is no visible cavitation at S = 6000 (cavitation inception) and that breakdown does not occur at a value of S less than 10,000. Failure to meet these conditions will be cause for disqualifying the bid for prototype pumps. Cavitation on a single blade only will not be considered cavitation inception. Over one-half of the blades must show similar "starting" cavitation patterns to represent the inception point for meeting $S \geq 6000$. Cavitation occurring on one side of the pump only will be considered visible cavitation if each blade in turn cavitates during the same portion of a revolution relative to the pump case. Thus, asymmetric cavitation in the pump is considered visible cavitation subject to the inception point limitation of $S \geq 6000$.

c. Laboratory Requirement (Independent Laboratory). --

1. Measuring Accuracy. -- The test set-up and instrumentation shall comply to the requirements of the Hydraulic Institute Test Code. Every attempt will be made to obtain an overall accuracy for the efficiency determination of plus or minus 0.1 percent. Instruments shall be accurately calibrated and an error analysis performed by the Independent Laboratory to establish accuracy as determined by the following calculation for the Engineer:

$$f_p = \pm \sqrt{(f_Q)^2 + (f_H)^2 + (f_T)^2 + (f_N)^2}$$

Where f is the amount of inaccuracy and the subscripts refer to:

p	=	overall efficiency
Q	=	capacity measurement
H	=	head measurement
T	=	torque measurement
N	=	speed measurement

2. Approval of Facilities and Equipment. -- The Engineer will be responsible for approval of the Independent Laboratory. All instruments shall be calibrated before testing. Calibration will include all primary and secondary elements traceable back to recognized standards. At any time during the test program that an instrument appears to behave improperly or if the Engineer requires a check, the instrument shall be re-calibrated in the presence of the Engineer. The Contractor may direct requests for checks on the laboratory and its instruments to the Engineer and, if the Engineer approves such request, a re-calibration will be performed. Retesting will be required of all tests that might have been affected by deviation of instrument performance as determined by the Engineer.

d. Test Report - Official Test. -- The Independent Laboratory will supply test reports to the Engineer, giving all data, instrument calibrations, calculations, curves and official efficiency value. The Engineer will make copies of the test report available to each Contractor for his model only.

In addition to curves for the actual test values, the Independent Laboratory will supply "normalized" curves giving head and flow rate and power in terms of:

$$\frac{H}{H\ \text{rated}}\ ; \qquad \frac{Q}{Q\ \text{rated}}\ ; \qquad \frac{\text{power}}{\text{rated power}}$$

Efficiency will be plotted on these normalized curves.

Cavitation performance curves will give head vs. NPSH, efficiency vs. NPSH, and on the same curve sheets the NPSH for cavitation will be noted. A curve of NPSH for cavitation inception and of NPSH for cavitation breakdown vs. Q will also be prepared. Corresponding σ values will be plotted also.

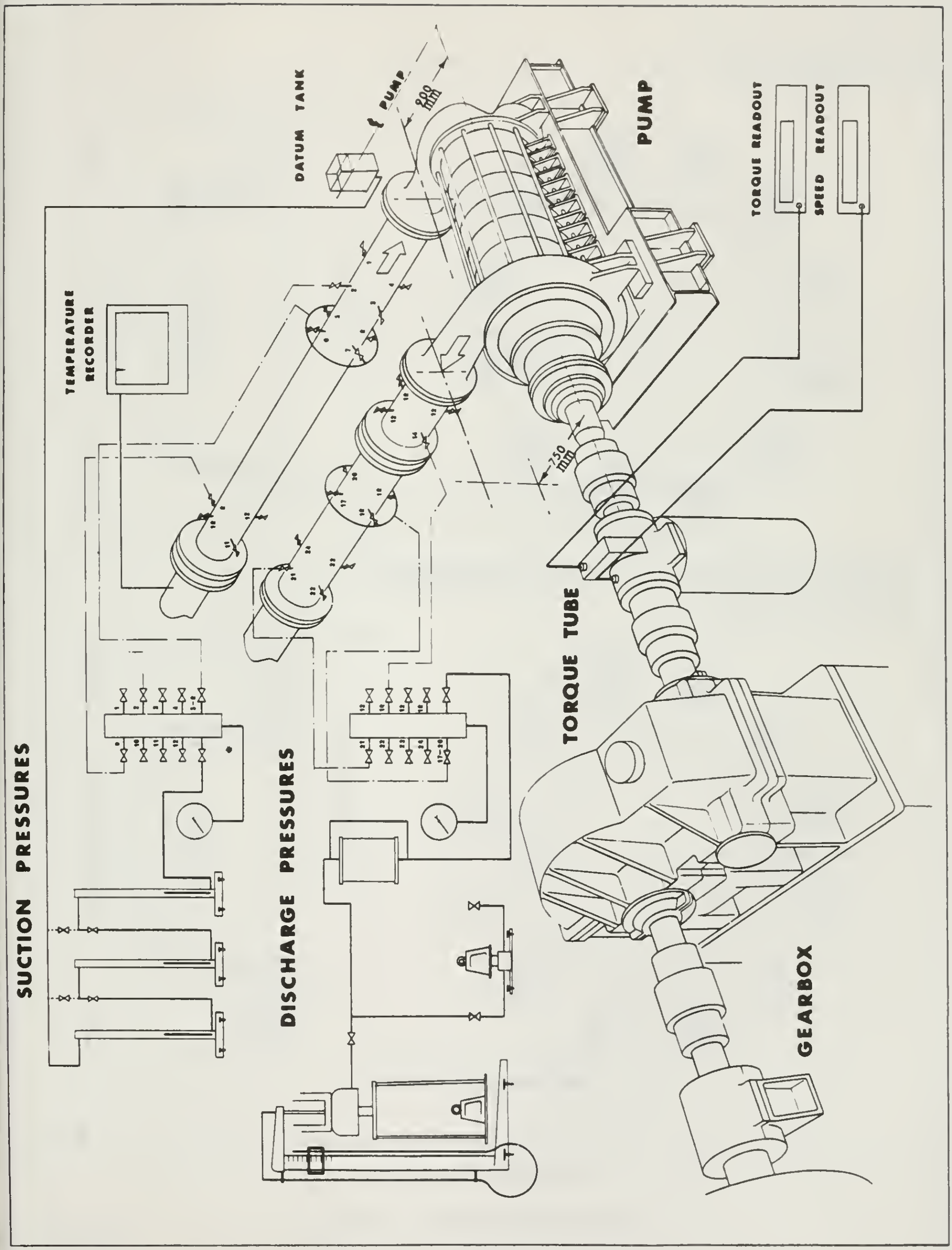
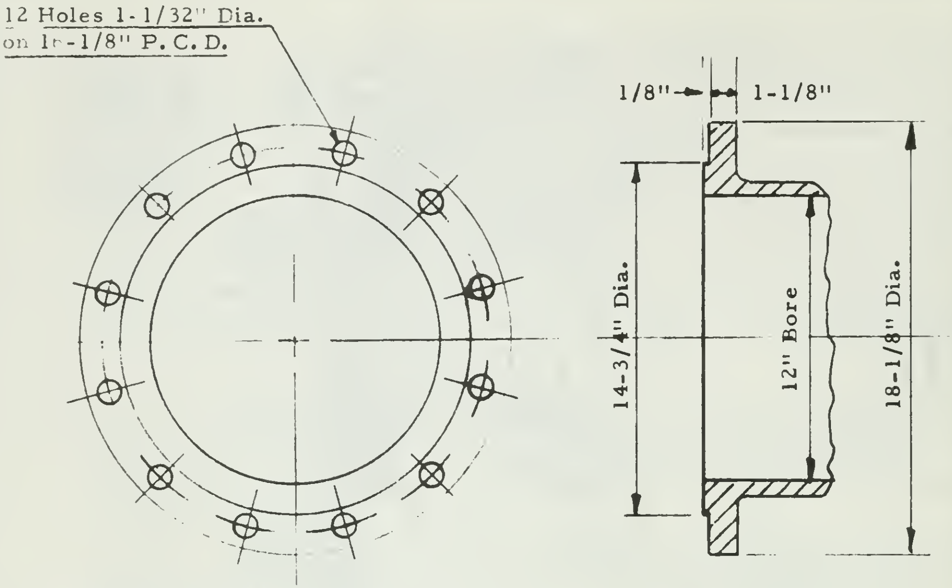
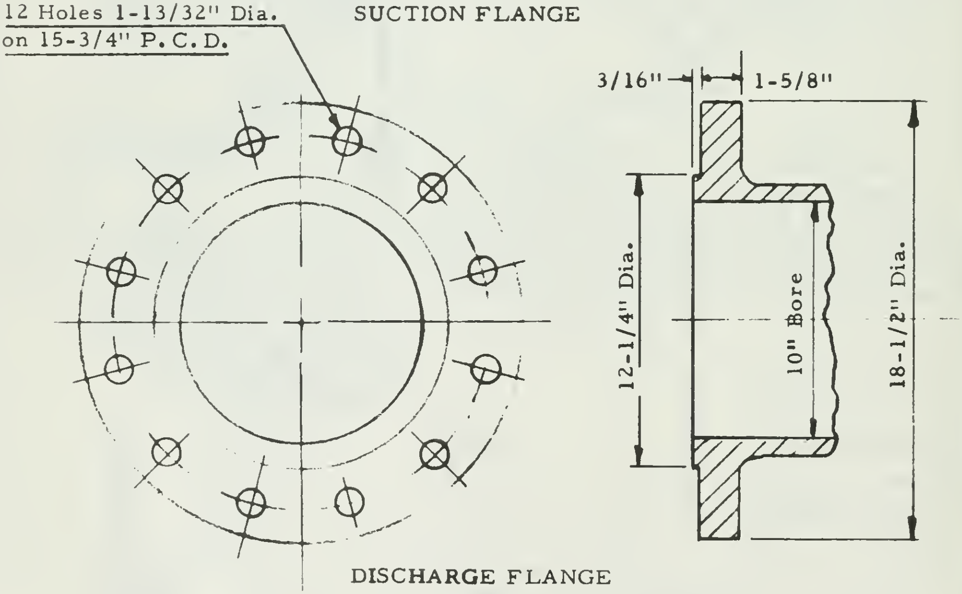


FIGURE I TEST ARRANGEMENT



SUCTION FLANGE



DISCHARGE FLANGE

FLANGE DIMENSIONS

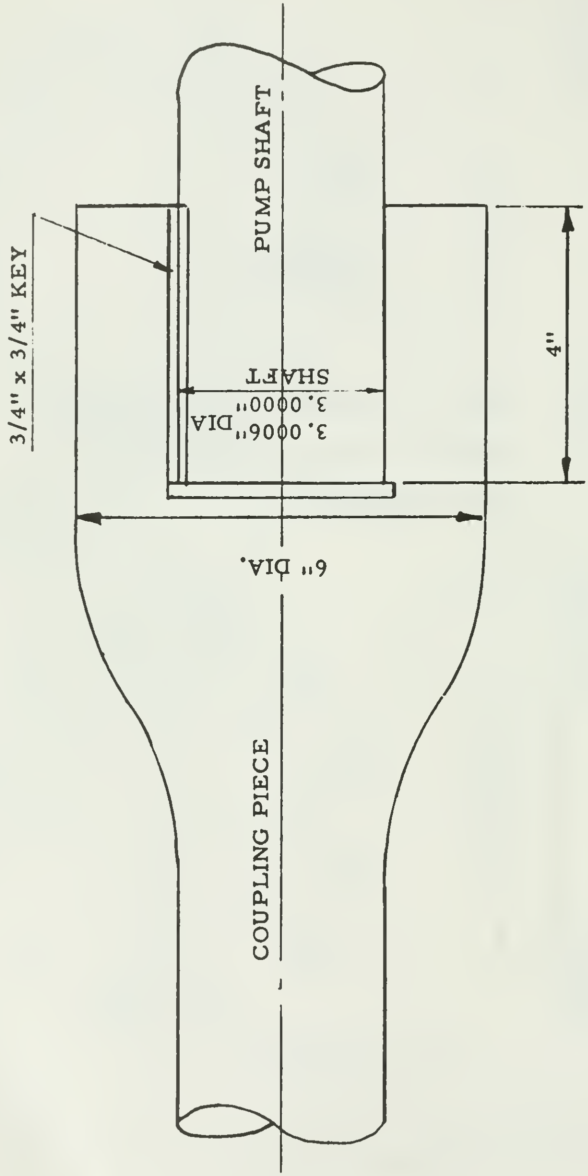
TEHACHAPI 4-STAGE MODELS

SCALE 1/6

FIGURE 3

Will be supplied when dimensional details of the mounting base have been finalized.

FIGURE 4



COUPLING BETWEEN PUMP AND TORQUE SENSOR

III. COMPARATIVE TESTING OF MODELS BY THE NATIONAL ENGINEERING LABORATORY

FORM F.C. 13A

MINISTRY OF TECHNOLOGY

Daniel, Mann, Johnson &
Mendenhall,
Los Angeles.

................................Research Station,
National Engineering Laboratory,
East Kilbride,
Glasgow, Scotland.

APPLICATION FOR TEST OR INVESTIGATION RY/14/6631

I/We desire to apply for the test or investigation described below, subject to the conditions stated on the back of this form.

Materials etc. to be tested	Patent No. (if any)	Nature of investigation or test
		Tests on Manufacturers' Models for Tehachapi Project, as detailed in Exnibit A attached hereto.

Fee: Not to exceed £42,500(Forty-two thousand five hundred pounds) without reference to us/me.

Cheques should be made payable to the Ministry of Technology and crossed Bank of England A/c H.M. Paymaster-General.

Signed ....
Irvan F. Mendenhall, President

Date 20 October 1966

(4543)

NOTE

Tests or investigations are carried out only at the discretion of the Director of Research acting on behalf of the Ministry Reports are not intended for use in legal or arbitration proceedings, especially those which might involve the attendance of members of the staff.

CONDITIONS

Tests and investigations are subject to the following conditions:-

1. The Ministry reserves the right to decline any proposal for the undertaking of a test or special investigation.

2. All materials, equipment, etc., to be tested or investigated shall be delivered, and collected, at the cost of the applicant, and in accordance with the requirements of the Ministry.

3. No liability shall be incurred by and no claim shall be made against the Crown or any servant or agent of the Crown or any person employed at the Research Station in respect of any loss or damage to any of such materials, equipment, etc., occuring at the Research Station or in the course of transit to or from the Research Station, and whether or not resulting from any act, neglect or default on the part of any servant or agent of the Crown or any person employed at the Research Station.

4. The Ministry does not accept any responsibility for loss or damage arising from the use of information contained in any of its reports or in any communication about its tests or investigations.

5. The estimated fee for the cost of the work, will be quoted in advance, and this estimate will not be exceeded without reference to the applicant.

6. Fees are prepayable, and should accompany this form.

7. Tests will not be made on proprietary or patented materials unless all particulars, including the composition and method of manufacture, are disclosed and can be indicated in the report.

8. If the test or investigation is required of a material or product which has failed in use or in connexion with any dispute, whether or not the dispute is the subject of contemplated or actual arbitration or legal proceedings, the circumstances must be fully disclosed by the applicant. In such circumstances the Ministry cannot undertake to place its services at the disposal of any one party. The investigation, if undertaken, and the subsequent report would have to be open to all parties who would be expected to provide either at their own initiative or on request any relevant information and to agree to accept the Ministry's findings.

9. Availability of Reports

   (a) Reports involving third parties, such for example as those furnished in the circumstances indicated in 8 above, may not be published in whole or in part or in abridged form by any of the applicants. The Ministry, however, reserves the right in its absolute discretion to publish such of the results of any such investigation as it deems to be of general interest.

   (b) Reports not involving third parties may be freely published by the applicant, except in, or in connexion with any Company prospectus or similar publication, provided that such publication is verbatim and in full. If the Ministry notifies the applicant that it is seeking patent protection as provided for in condition 10, the applicant will be required to undertake not to publish any report without the prior consent of the Ministry. No extract from or abridgment of any report may be published without the prior consent of the Ministry, nor may any report be published (in whole or in part) in, or in connexion with, any Company prospectus or similar publication without such prior consent, which if given, may, in both cases be subject to conditions. The Ministry reserves the right to publish the results either in whole or in part together with any comments and additional matter which it thinks desirable, but will not in general expect to exercise that right except as regards results deemed to be of general interest. The Ministry will in any case consult the applicant beforehand.

10. If during the progress of the tests or special investigations discoveries are made originating with the Departmental officers concerned and relating to the subject-matter of the tests or special investigations, the Ministry may, after consulting the applicant, but in its absolute discretion, secure the ownership by patent, registered design or copyright in Great Britain and Northern Ireland or elsewhere, and the applicant shall be entitled to use the discoveries so secured by patent, etc., as follows:-

    (1) In Great Britain and Northern Ireland—under a free non-exclusive, non-transferable licence.

    (2) Elsewhere—under a licence or otherwise, but in all cases on such terms as may be determined by the Ministry in its absolute discretion.

(5889) Wt.43319/7046 3 1/65 G.W.B.Ltd. Gp.863

EXHIBIT A

The following requirements and conditions are attached to and made a part of the Application for Test or Investigation RY/14/6631; form FC 13A of the Ministry of Technology, National Engineering Laboratory, East Kilbride, Glasgow, Scotland.

Details of the Test Program for testing Manufacturers' Models for the Tehachapi Project are as follows:

1. Parties to the Program

This application for test and the resultant contract with the National Engineering Laboratory, Ministry of Technology, East Kilbride, Glasgow, Scotland (to be known as the "Laboratory") is made by the firm of Daniel, Mann, Johnson, & Mendenhall, Los Angeles, California (to be known as the "Engineer") in behalf of the Resources Agency of California, Department of Water Resources (to be known as the "Department"). The Laboratory is to carry out performance tests on three models submitted by three Contractors:

Allis-Chalmers/Sulzer Bros. (AC/S)

Baldwin-Lima-Hamilton/J. M. Voith (BLH/V)

Newport News Shipbuilding and Drydock Co./
Escher Wyss (NN/EW)

The test results provided by the Laboratory are to be employed by the Engineer in assisting the Department in an evaluation of bids for the prototype pumps for the Tehachapi Pumping Plant.

2. Scope of Work

a. General

The Laboratory shall conduct H, Q, efficiency and cavitation tests on three pump models. The models will all be 4-stage, horizontally mounted units with impeller diameters of 15 to 15.5 inches, and will be hydraulically homologous to the prototype pumps for the Tehachapi Pumping Plant, California. Performance of the prototype and the required test performance conditions for the models are given in DMJM Specification No. 637-1-2 entitled "Specification for the Design, Fabrication and Testing of a 4-Stage Pump Model for Tehachapi Pumping Plant, California." The Laboratory will conduct the "Official Tests" as outlined in Article (d), Section (2) of the Specification. The tests will be performed during the period May 1, 1967 to August 31, 1967. Preparatory work necessary before the start of testing will be completed before May 1, 1967.

b. Items of Work

The Laboratory will perform the following items of work:

(1) Preparatory Services

(a) Provide details of existing laboratory facilities for guidance of the model manufacturers in the design of mountings, pipe flanges and locations, shaft extension, etc.

(b) In cooperation with the Engineer, prepare formal, detailed test procedures to be applied identically to all models.

(c) Equip laboratory with additional materials, pipe connections, instruments and accessories necessary for conducting the tests.

(2) Model Tests

(a) Conduct H, Q, efficiency, cavitation tests on Model No. 1, and reduce data and calculate efficiency points to be used in preparation of the official efficiency curve. Prepare an informal written report of results (which may consist of computer print outs and necessary plotted curves) for the review and approval of the Contractor. A copy of this report shall be available to the Engineer but stored in the NEL safe.

(b) Test Model No. 2 as in (a) above.

(c) Test Model No. 3 as in (a) above.

(3) Reports

(a) Laboratory Reports

Prepare a report on laboratory facilities and instruments to be used in the test work and include all calibration data, certifications of accuracy, etc. associated with the instrumentation that will be complete before testing commences. A copy of the complete test procedure, Item (1) (b), shall be included with the Laboratory Report. Twenty-five copies and one reproducible copy[1] shall be submitted to the Engineer.

---

[1] Transparencies suitable for producing direct positive prints on DIAZO AMMONIA paper.

(b) Final Report

Prepare a historical summary of the test program and provide in one report the test results for all three models to include all laboratory test data, calibration data, etc., obtained during the course of testing, calculations and performance curves. This report will be a formal and complete reporting of the information produced informally as a part of the model test work, items (2) (a), (2) (b), and (2) (c) and will include the report material held in the NEL safe for DMJM during the course of the program. Any auxiliary data and information will be added along with photographs of the models on test and photographs of other laboratory equipment not presented in the Laboratory Report ((a) above).

Twenty-five copies and one reproducible copy shall be submitted to the Engineer.

3. Schedule

Item (1) (a) - Major details by October 1, 1966, other information as required.

Item (1) (b) -
Outline by November 15, 1966.
Rough draft by December 15, 1966.
Draft for Contractor review by January 15, 1967.
Receive Contractor comments February 15, 1967.
Final test procedure issued March 15, 1967.

Item (1) (c) - All equipment and piping sections for all three models shall be completed by April 15, 1967.

Item (2) (a), (b) and (c) - Start installation of first model by May 2, 1967. Install and complete testing of all models by August 31, 1967. (The first model is expected to be available May 1, 1967 and the second and third models are expected on June 1, 1967.) An arbitrary method shall be used in selection of the order of testing for the second and third models. The performance data will be processed and the informal written summary (computer print outs and plotted curves) submitted to the Contractor and the Engineer within 24 hours after the completion of the performance tests.

Item (3) (a) - The laboratory report shall be submitted by May 1, 1967.

Item (3) (b) - The final report shall be submitted within 30 days of the bid opening for the first lot of the Tehachapi pumps.

4. Confidential Treatment of Test Results

The test results will have great value in the evaluation of bids for the Tehachapi pumps and therefore every precaution must be taken to insure that test results remain confidential until the opening of bids for the prototype pump by the Department. The Laboratory agrees to exercise every possible means of keeping the test data and events of the test program confidential and assist the Engineer in this endeavor as well. The security methods to be employed will be detailed in the written test procedure and will include such measures as limiting and keeping records of the dispersement of all laboratory and calculated data, instructing and otherwise controlling laboratory technicians regarding security and by imposing physical control of laboratory personnel, observers, visitors, etc. with regard to the test area and data treatment and storage areas.

5. Special Conditions

a. Termination

The Engineer may in its absolute discretion terminate the Laboratory's performance of the work under the Application for Test or Investigation, in whole or from time to time in part, by written notice to the Laboratory. Such termination shall be effective in the manner and upon the date specified in said notice. In the event of such termination the Laboratory will be paid a fee in an amount equal to the total fee earned for services rendered to the effective date of such termination subject to the not to exceed amount set forth on the Application, less the sum of all payments theretofore made to the Laboratory for such services. Upon the receipt of such notice of termination, the Laboratory shall deliver to the Engineer one clearly legible copy of all reports, data, findings and other writings prepared, developed or otherwise in its possession directly related to the services for the Engineer, up to the effective date of termination. A reasonable charge may be assessed the Engineer for services associated with clearing models from the Laboratory and for necessary work required to fulfill the above provisions.

The Laboratory shall provide for termination in the manner described herein when executing subcontracts. Upon receipt of written notice of termination from the Engineer, the Laboratory shall immediately give notification of termination to subcontractors affected and shall notify the Engineer of those subcontracts so terminated. The Engineer will compensate the Laboratory for the subcontract charges and costs associated with a terminated subcontract. In certain instances, the Engineer may direct that subcontract work be completed in which case the Laboratory will be compensated for the costs incurred.

b. Final Completion

All services required to be performed by the Laboratory shall be completed on or before October 30, 1967, except if the Engineer delays the services of the Laboratory.

c. Method of Payment

Daniel, Mann, Johnson, & Mendenhall agrees to pay a deposit of Three Thousand Pounds (£ 3000) with this application to be applied to the total costs for the services performed. Billings and payments will be made on a quarterly basis.

d. Purchases

All purchases made by the Laboratory to be charged to the Engineer must be approved prior to purchase by the Engineer if the amount of the individual purchase exceeds £ 175.

e. Travel Authorization

All travel by Laboratory personnel in conjunction with the subject of this agreement must have the prior, written approval of the Engineer. Local travel within a 50 mile radius of the Laboratory is excluded.

f. Department Approval

All conditions of this Exhibit A attached to the Application for Test or Investigation are subject to the approval of the Department of Water Resources, The Resources Agency of California.

Not for distribution outside NEL, DWR, DMJM and their nominees, and the pump manufacturers concerned.

FLUIDS MEMO No 272
REVISED VERSION AS AMENDED BY OBSERVERS BRIEFING MEETING 18th to 20th APRIL, 1967

Laboratory Procedure Report
for the conduct of the evaluation tests at NEL on the
Tehachapi Model Pumps

by

Dr. E. A. Spencer
(head of Fluid Mechanics Division)

and

Mr. R. A. Nixon
(Chief-of-Tests, Fluid Mechanics Division)

Fluid Mechanics Division,
National Engineering Laboratory,
East Kilbride,
Glasgow,
Scotland.

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PRINTER'S NOTE

It was originally intended that the draft copy of this Laboratory Procedure Report circulated by DMJM, Los Angeles before the Observers Briefing Meeting and the issue with minor revisions distributed by NEL at the Meeting on 18th April, 1967, would be replaced by a FINAL REPORT printed to the normal NEL standards.

By Dr. Spencer's decision, to save time and to save the need for recipients to re-check the whole report again word for word, the report has been re-typed and traced only where essential, as shown by the marginal indication.

Apologies are made for the lower quality of presentation.

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FOREWORD

This Laboratory Procedure Report has been prepared by NEL staff after consultation with DMJM/MC representatives and others who have given advice and comment. Its purpose is to provide a detailed guide of the way in which the Tehachapi bidders' model pump tests will be carried out and thus to ensure that observers at these tests are fully acquainted beforehand and agree to the programme as planned.

Apart from NEL staff who will carry out all the actual measurements, staff from the Ministry of Public Building and Works (MPBW) assist by providing mechanical and similar services to NEL and by controlling the electrical side of the operation of the high-power 11 000 volt A.C. motor. Power for this motor is supplied by the South of Scotland Electricity Board (SSEB) and permission must be sought from the local controller each time the motor is started up. NEL acknowledge the co-operation given by MPBW and SSEB in carrying out the planned programme.

At the Observers Briefing Meeting, held at NEL from 18th to 21st April, 1967, this report was examined in detail. Overall acceptance of this Laboratory Procedure Report was given once the amendments discussed during the meeting were included; the Revised Version incorporates all these. All technical changes from the previous April 1967 version are indicated by a vertical line in the margin: typographical mistakes or omissions have been corrected but these are not marked.

Antony Spencer

R A Nixon.

1st May, 1967.

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1. INTRODUCTION

It is essential to the success of the forthcoming Tehachapi bidders model pump tests at NEL that all those taking part and especially the observers from outside NEL should be fully acquainted with the purpose of the tests and the manner in which they will be carried out. The purpose of the tests is laid down in the 'Specification for the Design, Fabrication and Testing of a 4-stage model pump for Tehachapi pumping plant, California, Specification No 637-1-2' prepared by Daniel, Mann, Johnson and Mendenhall, Consultants to the Department of Water Resources, State of California(1). In essence it is that

> 'Testing for H, Q, efficiency and cavitation will be made to ensure compliance with specified rated conditions and for utilizing the efficiency of manufacturer's models in a prototype bid evaluation'.

This report describes, therefore, not only how the equipment and methods to be employed have been designed to work, but also itemizes and examines all the known sources of error.* After describing the general layout and control of the tests, the Report goes on to each in turn of the measuring stations manned by individual members of the test team - speed and torque, inlet head, discharge head, and flow measurement. The installation, maintenance and preparation of all parts of the test rig are examined and the calibrations, as well as the methods of measurement associated with each of the test stations, are dealt with. Various subsidiary measurements such as temperature and barometric pressure, and other aspects such as photographic records, are also described.

A section is devoted to a statement of the way in which the test data will be processed, including details of the equations and the constants used, in order to evaluate the performance of the model pump. This section also includes notes on the analysis of the computed performance results to obtain the characteristic performance curves by the method of least squares, from which the maximum efficiency value is then determined.

Finally, security rules for these tests are laid down. The Laboratory has a responsibility for the safety of personnel and the safe-keeping of information provided to NEL staff or obtained by them in the course of the tests. Clearly it is also in the interests of the manufacturer that all data obtained on his pump should be confidentially treated. The rules given in this section ensure that security will be maintained at the Laboratory; they have been prepared in collaboration with the DMJM/MC representatives and also cover the latter's area of responsibility. It is expected that all parties involved in the tests will co-operate in carrying out these rules.

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*Errors quoted in this report have been estimated on the basis of 95 per cent confidence limits: this means that, on average, nineteen out of twenty observations of the quantity can be expected to lie within the quoted limits.

2. The High-power Pump Test Rig

The pump test circuit is shown in Fig. 1(a). Water from the main 7200 ft^3 capacity sump in the Reynolds building is supplied at controlled pressure to the model pump suction via three booster pumps. Nos 1 and 2 booster pumps are the No 1 and 2 service pumps installed for general use in the main laboratory. They can be used singly or in parallel as required. Each is driven by a 200 hp d.c. motor with a controlled speed range 400 to 700 rev/min. They draw directly from the main sump, and their discharge is led to No 3 booster pump situated in the basement of the building. No 3 pump develops a relatively high head, and is driven at 985 rev/min by a 445 hp induction motor. Water from this pump is led to the model pump on test in the pump house.

Although the No 3 pump runs at a nominal constant speed, its boosting capacity is controlled by the use of a 12-inch bore bypass line and two valves. One valve, designated No 5, is in the bypass line, and the other, No 4, at the pump discharge, as shown in Figs 2(a) and 2(b). Thus for maximum Net Positive Suction Head (NPSH), Nos 1, 2 and 3 boosters run at full speed, No 3 booster discharge valve is fully open, and the valve in the 12-inch bypass line is fully closed. For minimum NPSH without throttling, only No 1 pump runs at its lowest speed, Nos 2 and 3 boosters are stopped and isolated, the latter with discharge valve No 4 closed and the 12-inch bypass line valve No 5 fully open. This condition may be expected to correspond to lower pressures at the model pump inlet at the full speed duty flow than will be necessary for the official bidders model cavitation tests. However, lower values of NPSH may be attained if required by further throttling of the 12-inch bypass valve. Fig. 3 shows the maximum NPSH available for the tests.

The discharge from the model pump passes through three pressure breakdown valves.(2) No 1 valve, specially designed by the Darling Valve Company for the Tehachapi model duty, is situated in the pump house pit and breaks the discharge pressure down to a value within the high pressure safety limits of the main laboratory (250 lb/in^2). No 2 valve, designed by NEL and designated No 76 in the main laboratory, is in the basement of the main building and breaks the pressure down still further to suit the limits of the re-absorber (60 lb/in^2). Any air which may have come out of solution from the water during its passage from the sump through the pumps is redissolved in the re-absorber. From here the water passes through an 18-inch electromagnetic flowmeter and on to the final No 3 breakdown valve, which is a spear valve above the diverter and weightank. This final valve serves two purposes: first, to maintain sufficient back pressure to ensure a stable jet, and second, to provide for very fine flow control. The water passes from this point back to the sump, as described in Section 4.4. The three control valves are shown in Figs. 4, 5 and 6.

The 4000 hp, 11 000 V, 3 phase, 50 cycle synchronous motor (Fig. 7) operating at 750 rev/min, which drives the model pump through a double-helical gear type speed increaser, with interchangeable gear ratios for various speeds. The gears available provide speed outputs very close to 1500, 1750, 2000, 2250, 2500, 2750, 3000, 3250 and 3500 rev/min.

A strain gauge type torque sensor,(3) supplied by Lebow Associates Inc., is used to measure the driving torque in the shaft between the gearbox and the model pump. A speed sensor is incorporated with the torque measuring equipment. This torque tube is shown in Fig. 8.

Straight lengths of pipe similar in diameter to the inlet and outlet diameters of the model pump are installed upstream and downstream of the pump under test. Details of the pipe configuration in the vicinity of the models are given in the NEL drawing No Y2/03899, 'Piping arrangement for Tehachapi evaluation tests' which is reproduced in Fig. 44. Fig. 9 shows the pressure tapping positions in these head measuring pipes.

The temperature of the water in the system would rise more than 4°C per hour at full model speed conditions if no cooling were available. Control of temperature is achieved by four forced draught cooling boxes mounted in the open near to the Reynolds building. Water is pumped continuously from the sump into as many of the four towers as are needed. After cooling, the water flows by gravity into two covered vented tanks, from which it is pumped back to the sump. This cooling can be monitored and controlled from the Pump Test House.

3. PREPARATORY WORK BEFORE TESTING

The work can conveniently be divided under four logical headings:

A. Maintenance of plant in good running order so that the schedule can be maintained throughout the test series.

B. Maintenance of testing equipment to ensure high and consistent accuracy of test results for all pumps.

C. Preparation of observers and test team.

D. Preparation of data processing.

Items under heading 'A' above are primarily the responsibility of NEL insofar as this heading excludes all items which can have any bearing on the accuracy of tests, or on the validity of the comparison between the test results of the various bidders' models. However, it is described in full detail in this section, as its importance is recognized for the tests to run as smoothly and with as little interruption as possible.

Items under heading 'B' will be the especial concern of all parties involved. For this reason and as part of the programme under C, Section 4 not only describes the procedures involved, but also discusses fully the possible sources of error, not all of which might be apparent to even a skilled observer were they not brought to his notice.

Each of parts A and B can be further subdivided into long term and short term work. It will be appreciated that the full breakdown, inspection and maintenance of all the test complex would take several months, even if it were possible to halt all the Laboratory's work in order to perform the task. The time schedule would not allow this to take place between the tests of the various models. It will, however, be done during the six months preceding the start of the programme. The long term work in this category comes mainly under heading A above.

The major exception is the full static calibration of the weightank, which is the standard against which flow is measured, and therefore comes under heading B. This will be calibrated immediately before and shortly after the bidders' model programme[7]. In between the tests of the different models only checks will be carried out, as described later. While it is desirable and possible, however, to check and calibrate the other measuring equipment much more frequently, enough experience and data has been amassed over the past eight years concerning the long term stability and reliability of the weightank calibration to be satisfied that the two full calibrations separated by a time of only six months are adequate to maintain proved consistency within the required limits of accuracy. This is illustrated in Table 1 and a more detailed account is given in Reference 4.

The programme of preparatory work leading up to the start of the test programme will be given in outline and then followed by a detailed description of the installation of a model pump.

3.1 Primary circuit

3.1.1 Primary loop pipework

Much of this is in constant use for other Laboratory activities, and is thus being continuously checked for leaks, undue corrosion etc. The only items in this section of the loop which could give trouble are the right-angled vaned pieces ('cascade bends' Fig. 11) between Nos 1 and 2 low-head boosters drawing from the sump and the No 3, 400 hp high-head booster. There are four of these, each of which has been removed, inspected and, where necessary, strengthened during the six months preceding the tests. Re-inspection will not be necessary during or even shortly after the tests. However, in addition to this precaution, a $\frac{1}{2}$-inch mesh filter has been placed in the line between the last cascade bend and the No 3 booster pump. This will safeguard the No 3 booster pump against any damage. Another similar filter has been placed in the line downstream of No 3 booster pump. This will safeguard the $\frac{1}{8}$-inch mesh filter upstream of the model pump section (see Section 3.2 dealing with: 'Installation of Model Pumps'). The location of filters is given in Fig. 1(a), 2(b) and 44 and full details of all filters in the primary loop are listed in Table 9.

3.1.2 Primary loop valves

(a) Isolating valves in line

These valves are used only in their 'open' or 'closed' positions, are not used for regulation, and are not required to provide 100 per cent stoppage of flow. Only two functions are essential to the success of the tests:

(i) that they will open fully and remain open,

(ii) that water will not leak out past the spindle seal to atmosphere.

Both of these functions are checked in the daily use of these valves in connection with other work. It is proposed only to keep a particular check during the week preceding the test programme. Any defect discovered could be remedied within a few hours.

(b) Regulating valves

It is important that these valves

(i) can be moved to any required position in their travel and maintain that position precisely and indefinitely under the test conditions,

(ii) operate satisfactorily under remote control, and

(iii) do not leak to atmosphere.

Diagrams of the regulating valves are shown in Figs. 4, 5 and 6. Valves on the inlet side between the boosters and the model pump are simple gate or butterfly valves. Their operation will be checked one week, and finally one day, before the start of the test programme for each individual pump.

Discharge valves are more complex and any faults in operation could lead to serious delays in the programme. Proposed actions will be as follows.

Breakdown Valve No 1 (Fig. No 4)

This was completely stripped, examined and re-assembled in September 1966 following over twelve months of use in the MWD phase of the Tehachapi programme, involving six pumps. No signs of damage or malfunction were discovered, and it is not proposed to strip this again until after the bidders' model tests have been completed.

The actuating mechanism underwent a complete overhaul in November 1966. It is not proposed to strip this again as it has continued to give satisfactory service during the preparatory testing programme in February/March 1967.

Breakdown Valve No 2 (Fig. 5)

This was last stripped in 1962. It was given a complete routine maintenance overhaul in March 1967.

Breakdown Valve No 3 (Fig. 6)

This was inspected and overhauled during the weightank calibration and sump cleaning operations in March/April 1967.

3.1.3 Leakage Checks

The only leakages which need be considered for possible effects on the model pump tests are those either out of or into the part of the circuit connecting the pump discharge flange to the weightank.

These possible sources of leakage can be classified as follows

(a) leaks to atmosphere

(b) leaks to closed circuits or dead spaces in parallel with the model pump discharge line

(c) leakage between pump suction and discharge lines.

(d) leakage into the sump

Leaks to Atmosphere

In general, any significant leak to atmosphere will lead rapidly to obvious flooding. The exceptions are as follows.

(i) Leakage into Constant Head Tank (CHT)

This vessel has a cross-sectional area of about 250 ft^2 and a capacity of approximately 18 000 US gallons. Leaking valves could allow flow to enter this either from the pump suction or the pump discharge lines (see Fig. 10, valves 93, 25, 11 and 8). In order to check for leakage, the tank will be emptied before the start of each night of test to such a level that the source of any leakage can be immediately detected and traced to its source. The data collector will be stationed at the constant head tank between the times of starting the No 1 booster and setting up the flow (nominal time as given in Table 5, 2020-2104) to check for any leakage. If observed, such leakage will be reported immediately to the Chief of

Tests, who will delay the start of tests until he, the DMJM/MC Engineer, and the manufacturer are satisfied that the trouble has been cleared.

(ii) Leakage to Variable Head Tank (VHT)

The VHT is the tall yellow-painted tank of pear-shaped cross-section (sectional area about 40 ft^2) extending from the basement to the top floor of the Reynolds building. It is isolated from the primary circuit through valves 37, A and 48 (Fig. 10). This tank has a level indicator marked in feet, inches and tenths of an inch, with readouts both on the ground floor and the top floor of the Reynolds building. The data collector will note if any change has taken place in the tank level each time he passes between the Test House and Station 5.

Leaks to closed spaces

During the day other circuits will be in use in the Laboratory. Because of the general use of the weightank for pump, turbine and flow-meter testing these circuits must be interconnected with the Tehachapi Bidders' Model primary test circuit. At the end of each day they will be isolated by means of valves from this primary circuit. If they are broken down, any leakage through such valves will be to atmosphere, and be readily detected. If such leakage cannot be prevented by the isolating valves, blank flanges will be fitted. Where parallel circuits (for example, the closed pump test rig, the turbine water tunnel, the mixed flow pump rig, the outside line) remain closed, they will be kept full of water.

It is impossible to give a complete statement predicting the state of these circuits to cover the period of test programme on the three bidders' pump models. This will be discussed fully, however, before the start of each test series with the Chief of Tests, who will issue a check list to the Official Observers, and will keep this updated on a daily basis throughout the tests. These check lists must be initialled by NEL, DMJM/MC, and the manufacturer's representatives before leaving the site at the end of a night's run. The lists will then be held by NEL. Any leaks noted and the subsequent action taken will be recorded and noted in the Test Report.

Leakage between suction and discharge lines

Such leakage can take place only indirectly (and most improbably) via the Constant Head Tank, which has been dealt with above, and between the No 1 and 2 booster manifold via valves 37 etc. (Fig. 10). During the tests, valves 37, 48 and A will be kept closed, and a tube attached to a pressure tapping between 37 and the other valves. If any significant amount of water emerges from this tube, the line will be broken, and blank flanges fitted.

Leakage into the sump

This has been made impossible by fitting blank flanges to any lines which could bypass any of the pump discharge into the sump without going through the diverter. This was necessary because leaks in this category would be virtually undetectable.

3.1.4 Sump

The main Laboratory sump was emptied and cleaned during the first fortnight in April 1967 as part of the Laboratory annual maintenance routine. At the same time, the screens S6 and S1 (see Table 7) between the diverter and the main body of the sump and at the suction intakes to Nos 1 and 2 booster pumps were inspected and cleaned.

3.1.5 Booster pumps

(a) Nos 1 and 2 service booster pumps

These pumps are in daily use throughout the year and their proved reliability is essential to all aspects of the Laboratory programme and not only the Tehachapi model project. Neither pumps nor motors are due to be stripped under the main planned maintenance programme, but a close check will continue to be kept on performance during the preparatory period. No difficulties are anticipated, but a final check will be made one week, and again one day, before the start of each model test.

(b) No 3 booster pump

This pump is only one year old and has given no trouble since the initial running in of the glands and bearings. During the preparatory period, the top cover was removed for inspection of impeller and flow passages, and the glands and bearings were inspected. No replacements were necessary.

3.1.6 Weightank emptying pump

This pump is in daily use. Its reliability is essential to the smooth running of all projects, including the Tehachapi model tests. It will be completely overhauled during March/April 1967 and seals will carefully be inspected before the start of each model test.

3.1.7 Secondary cooling loop

Although this loop is not absolutely essential to the successful testing of a model, failure would lead to delays owing to the rise of temperature with time which could curtail testing periods. It is being completely overhauled, including replacement of flexible pipes with steel pipes and provision of an extra pumping unit, during March/May 1967. Adequate cooling capacity supplied by forced draught cooling boxes was installed in March 1967. The system will be checked out one week, and finally one day, before the start of each model test series.

3.1.8 Drive arrangements to model pump - motor controls

The following statement was issued by the NEL Depot Superintendent of MPBW, dated 23rd December, 1966.

'The motor and associated equipment is serviceable and ready for operation now. Maintenance of the control panel has been carried out, the oil for the O.C.B.'s has been tested and the motor inspected before and after test runs, brushes are inspected and connections checked regularly, i.e. regular maintenance is a continuous process.'

It may be explained with regard to the above statement, that the standard maintenance schedule involves testing the oil for the oil contact breakers every two years, unless in the meanwhile they become accidentally overloaded. The fact that the oil was tested after a series of tests involving Tehachapi type duties and was found unaffected justifies the decision to keep to the standard maintenance schedule throughout the bidders model tests.

3.1.9 4000 hp motor

During January 1967 the motor was examined. Its performance was checked under load during January/March 1967 and some adjustments made. As a result high power tests were completed successfully in March 1967. Between March and May, and during all non-testing periods, it will be run light at least once weekly. Bearing covers will be lifted for inspection between tests. It is not now planned to have spare bearings available. The Ministry of Public Building and Works control all electrical and maintenance operations on the high voltage equipment and, in addition, their electrician will be responsible for checking motor and gearbox bearing temperatures during tests, and for ensuring the lubricating oil supplies.

3.1.10 Gearbox

All pinions to be used in the tests have been inspected and found to be in good condition. They have been inspected by NEL (and if required by observers) in their storage racks and/or in situ in the gearbox during April 1967 and subsequently an inspection will be made before each gear change. Bearings will be examined at the same time. The gearbox oil will be changed before each bidders' model test. The MPBW electrician will be responsible for the satisfactory circulation of lubricating oil and cooling water to the gearbox and for checking bearing temperatures during tests.

3.1.11 Auxiliary lubricating oil and cooling water supplies

Lubricating oil is continuously pumped through each of the main motor bearings while it is running. The gearbox oil is similarly circulated through the gearbox and an oil cooler. The cooler is supplied with continuous cold water. As stated in A9 above, maintenance of these services is the responsibility of the MPBW electrician during running periods. Their correct functioning will, however, be checked one week and then one day before the beginning of each bidders' model tests. Thereafter they will be checked daily by the dayshift throughout each test period.

3.1.12 Electricity

It will be appreciated that neither NEL nor MPBW are responsible for the supply of electricity. The suppliers, the South of Scotland Electricity Board (SSEB), cannot themselves give a 100 per cent guarantee of power availability when required. There is, however, no reason to anticipate trouble, especially during the summer months.

The SSEB have been informed about the period of the Evaluation tests. As soon as the final programme is agreed in detail, MPBW will be informed, and keep in close liaison with SSEB.

Clearance from SSEB during the tests will be checked at noon, at 20.00 hours, and obtained each night 15 minutes before the first start up, and immediately prior to each start up. This also will be the responsibility of MPBW.

3.1.13 Compressed Air

This service is provided daily to NEL by MPBW. It is vital to the use of the flow measuring system, and therefore not only to the Evaluation tests, but all other NEL work. This is explained in Section 4.4.7(i). It may be considered as completely reliable.

3.1.14 Water

Visual cavitation observations are affected by water quality. Water treatment (corrosion inhibition and filtering) is provided by MPBW. As soon as the test programme is finalized, MPBW will be asked to ensure adequate supplies of clean treated water, with maximum reserves, over the period of tests.

Water analyses will be made by the Chemical Analyst Department of the Corporation of Glasgow before and during the tests on the model pumps, and clarity measurements will also be made at NEL.

3.2 Installation of model pump

The sub-base plate is first to be secured to the test bedplate. The model pump is sited on top of the sub-base plate which has been calculated to bring the pump ℄ to approximately $\frac{1}{8}$ inch below the drive ℄. This $\frac{1}{8}$ inch is left in order that maker's manufacturing tolerances can be coped with in the final alignment of the model pump.

A shaft with a flange at one end, machined to mate with the pump flexible coupling is coupled to this coupling - see Fig. No 12. Two dial gauges are secured to the free end of the bar to allow the pump to be set accurately in line with the gearbox pinion. This is carried out by turning the pump shaft by hand thus making dial gauges revolve round the pinion coupling. The pump position is adjusted as necessary until the dial gauges indicate that the pump shaft and gearbox pinion are in line to the satisfaction of the manufacturers representative.

The piping is erected to the drawing with dial gauges positioned to check that no strain is put on the pump when the piping is finally connected to the pump casing. (See footnote on page 10)

Included in the piping arrangement is a sandwich flange built with a 1/16-inch stainless steel wire mesh across the bore. This sandwich flange is fitted at the pump end of the suction return bend and the differential pressure drop through the screen will be indicated by means of a manometer. Any increase in pressure drop at a given flowrate will indicate that the screen is becoming blocked. Previous to the tests this sandwich flange will be left out and another sandwich flange will be fitted in the suction line immediately preceding the pump suction flange. The pump and piping will be filled with water and the alignment checked. Water will be run through the piping and pump for a time agreed upon by the manufacturer, after which the sandwich flange will be removed and inspected to assure all parties that the line is free from foreign matter. Everything being to the satisfaction of all concerned, the sandwich flange at the suction bend will be installed and the piping closed up to the pump.

At this point a final alignment check will be made. The alignment will be checked at the start and finish of each night's test and noted in the log book and signed by both NEL and manufacturer's representative.

All instrument lines will be connected with nylon piping from cocks on the measurement section of the piping to the respective manifolds.

With respect to the check for foreign matter there are further $\frac{1}{2}$-inch mesh grids in the circuit which will exclude the larger pieces of foreign matter. These are situated over the suctions of Nos 1 and 2 booster pumps, at the outlet of No 3 booster pump and in the sump itself, as indicated in Figs 1(a), 2(b) and 44 and in Table 9.

The manufacturer's representative will be present during the check for foreign matter and at the final alignment check, and must sign approval in the pump log book before the model is coupled up.

4. OPERATION AND MAINTENANCE OF TEST EQUIPMENT FOR MEASUREMENTS

Under this heading, referred to as B in the previous section, each in turn of the measuring stations manned by individual members of the test team is dealt with. The information given is primarily to assist those observers responsible for countersigning test data sheets. In addition, therefore, to describing the basic physical principles and design of the various measuring techniques, the practical operational details required by the test team members themselves are also given.

Table 2 lists the test team stations required for the recording of data from which the performance of the models will be assessed. The test control station No 1 is included in the list, although the data collected here is from sub-standard sources, used for monitoring purposes, and never in any circumstances for analysing model performance. However, it does provide a co-ordinated record of the progress of the tests, and is therefore of value to observers as well as to the test controller. Similarly, station No 6, cavitation photography, must be considered rather in the sense of a monitor than as a source of absolute measurement, such as stations Nos 2, 3, 4 and 5. Station No 7 is included in the Table because it may be necessary to take measurements of bearing temperatures and cooling supply for monitoring purposes only.

Footnote to Section 3.2, paragraph 3, (page 9)

At the Observers Briefing Meeting 18th to 21st April, 1967, it was agreed that additional dial gauges would be mounted so that the manufacturer's representative in particular could be satisfied that no distortion of the pump took place during testing. The gauges would be read during the start-up and shut-down periods each night.

4.1 Control and communications - Station No 1

The operational control centre is situated in the Pump Test House. The test controller is given the agreed test programme for the night, and it is his duty to see that it is carried through as specified, subject to the safety of equipment and staff.

The control panel (Fig. No 13) therefore incorporates monitoring instruments which show the state of the test circuit continuously as follows:

Pressures

Pump suction
Pump discharge
Downstream of No 1 breakdown valve
Downstream of No 2 breakdown valve
Upstream of No 3 breakdown valve

Flow

Dial indicator graduated in cusecs from 18-inch electromagnetic flowmeter

Water temperature

Recorded on chart alongside main control panel (Read and officially entered on data sheet by No 3 station operator)

Auxiliary pumps

Nos 1 and 2 booster pump speeds
No 3 booster pump ('on' or 'off')

Valve positions

No 1 breakdown valve - digital indicator 0-285 turns
Nos 2 and 3 breakdown valves - dial indicators marked in inches of valve travel.
Nos 4 and 5 boost control valves - dial indicators marked in percentage opening.

All the above five valves are operable by the controller. No 3 breakdown valve is, however, normally operated by the weightank operator, by instruction from the controller, partly because this valve is in his area and under direct visual observation, and partly because he is in a better position to make fine adjustments to the flow by watching the electromagnetic flowmeter chart at the weightank. This chart is of a higher order of accuracy and precision than the dial indicator on the control panel.

Communications

The controller has an intercommunication system with the following positions: Stations 2, 3, 4, 5, (Table 2), the MPBW electrician and engineer responsible for the model pump. An improved system now being installed will allow for either individual or complete voice intercommunication between the above personnel as required by the test controller.

Co-ordination is further assisted by a system of light and sound signals.

An illuminated panel on the wall of the test house displays either 'Flow Change' or 'Flow Set' as appropriate. This is operated by Station 1.

An indicator box at Station 1 has an array of lights showing the state of readiness of the measuring stations 2, 3, 4 and 5. Red signifies 'Not Ready', Green 'Ready'.

A loud bell signal, worked in conjunction with the indicator box, is used to draw attention to the start and end of the following sequences of operations.

(i) One ring. Make final check of instrument settings and standby

(ii) Two rings. At the beginning of flow diversion period start taking readings

(iii) One ring. At the end of flow diversion period stop taking readings.

(iv) Three rings. Break sequence, for example before shutting down the main motor.

In the period of taking readings, between (ii) and (iii) above, a green light signal on the wall of the test house, operated automatically by the diverter mechanism at Station 5, will indicate that flow diversion is taking place. At all other times, a white light signal will be displayed. These bell and light signals are mainly for the behefit of observers and any others not provided with intercommunication headsets.

During the 'Flow Set' period Station 1 completes the control sheet, as shown in Fig. . The purpose of filling in this sheet is partly to provide control setting data for later flow settings, and partly to ensure that Station 1 does in fact check every significant control panel reading for each test point. The flow, pressures, speed etc. recorded on this sheet are of insufficient precision to be of value in pump performance evaluation, but do provide the controller with an adequate assessment of the state of the text complex.

The control sheet being used is shown in Fig. 14.

4.2 Torque and speed measurement - Station 2

4.2.1 Description of equipment

A line diagram of torque and speed measurement systems is shown in Fig. 15.

The measurement of torque is carried out by means of a Lebow torque tube and ancillary electronic equipment which enables a readout value of torque to be obtained[(3)]. To enable varying load ranges to be accommodated three interchangeable torque tubes will be in use. These tubes permit any range of load between 0 and 120 000 inch lb to be measured in steps of 0 to 48 000 inch lb, 0 to 72 000 inch lb and 0 to 120 000 inch lb within the ranges given in Table 3. These tubes, numbered 1 to 3 respectively, will be used only in the ranges given in Table 3.

The measurement of torque is accomplished by means of four electrical resistance strain gauges which are attached to the central shaft of the tube (Fig. 16). The electrical resistance strain gauges are connected to form a Wheatstone bridge circuit, the axis of which lies along the centreline of the torque tube shaft. This method of bridge installation prevents any possible unbalancing of the bridge circuit due to longitudinal bending of the torque tube shaft. The leads from the bridge are connected to four silver sliprings mounted on the central shaft. The connection from the slip rings to the readout system is effected by means of a set of eight carbon brushes with two brushes acting on each individual slip ring. A d.c. supply is applied to the bridge from the supply circuit in the readout system and under no load conditions the bridge is balanced.

When a torque is applied to one end of the shaft it is twisted through a very small angle relative to the opposite end of the shaft. The effect of this on the strain gauges unbalances the bridge and the voltage due to the unbalance is picked up from the slip rings by the carbon brushes and passed to the readout system, via a four-core cable.

Experience with the torque tubes has shown that it is inadvisable to use them with carbon brushes which are permanently in contact with the slip rings. The reason for this is that dust and dirt caused by wear on the brushes, after a period of time, results in inaccurate signals being received. This problem has been resolved by the use of retractable brushes which are lowered to make contact with the slip rings for the duration of each test point only. This means that the brushes are in contact with the slip rings for about 30 per cent of one night's run and signal instability is reduced accordingly. To ensure the accuracy of the signal from the brushes, a trace is taken on a U.V. $R_e$corder before and after each test point; under good conditions the trace obtained shows a relatively thin line on the light sensitive paper, but should the brushes become contaminated with dirt and dust to the point of giving inaccurate results then the trace shows as a very thick irregular line. This is unlikely to happen provided the brushes have been lifted between readings and if both brushes and slip rings were in good condition at the start of tests. If, however, a bad trace is obtained before the start of readings at a particular flow setting, the brushes must immediately be lifted. Normally this will clear the trouble, as any dust will be thrown clear by centrifugal force and windage. Fig. 17 shows typical 'good' and 'bad' U/V recordings.

If the trouble persists, the brush holder can be removed for inspection without stopping the pump, but as a last resort the motor may have to be stopped for a thorough inspection of the slip rings as well as the brushes. Undue wear or scratching of the rings can give rise to irregular signals. The only cure for this is to remove the torque tube and machine the rings back to their original condition.

If, for any reason, the trace taken immediately after a set of readings at a given flow setting is unsatisfactory, these readings shall be considered invalid. The readings at that flow setting shall be repeated after the trouble has been cured and a satisfactory trace has been obtained. Only those readings for which good traces have been recorded, immediately before and immediately after, shall be considered valid. The Chief of Tests will be responsible for deciding whether a trace is unsatisfactory and hence whether testing must be suspended for a long or short period before further test points can be taken. It must be emphasised, however, that the real purpose of taking u.v. recordings is to receive early warning of a deterioration of bushes and/or sliprings. The validity of a set of torque readings cannot be either proved or disproved by the quality of the trace. Dirt, damage, or wear between bushes and sliprings may lead eventually to erratic and inconsistent torque readings which would of course eventaully be detected either in the checking or the data processing. It is obviously preferable to be able to detect and remedy troubles of this sort immediately they start by the use of a monitoring device.

The speed of the pump is measured by a toothed (phonic) wheel which is attached to the central shaft of the torque tube. Attached to the outer casing of the torque tube is a coil wound on a permanent magnet. The magnet is mounted so that only a small air gap exists between the tip of the magnet and the teeth of the toothed wheel. As a result, a magnetic field exists across the air gap and when this field is altered by the passage of the gear teeth a voltage is produced. The frequency of this signal is directly proportional to the pump speed and the number of teeth on the wheel.

The readout system comprises a Vidar voltage-to-frequency converter and two counting devices giving visual readings of speed and torque. The bridge signal voltage is converted to frequency in the Vidar converter, and passed to the torque readout counter which counts the frequency, integrates the count over a 10 second period and visually indicates the frequency every 10 seconds. Provision is made to enable the U.V. Recorder to be electrically connected to the Vidar, via an amplifying system, in order to obtain the traces previously described.

The speed readout counter counts the frequency of the signal from the pickup on the torque tube and outputs it in the same manner as the torque readout counter.
A view of the torque and speed instrumentation is shown in Fig. 18

4.2.2 Position of equipment in test house

The torque tube is mounted on a pedestal between the pump shaft and the output shaft from the gearbox. It is connected to each of these shafts by means of flexible couplings. It is important to ensure that the tube is mounted so that the torque measured in the pump tests is in the same sense (direction) as the torque applied for the torque tube calibration. On the calibration rig, the loads are applied to the right hand scale pan, facing from the torque tube to the 20-ft lever arm (Fig. 19). The corresponding position in the pump test house can be checked as follows. There are two pickup points from the body of the torque tube. The lead from the centre point (i.e. halfway between the ends of the tube) transmits the signal from the brushes to the torque readout equipment. The lead from the other point, which is offset from the centre, transmits the pulses to the shaft speed counter. When correctly mounted, the speed pickup point is between the torque pickup point and the gearbox coupling. If mounted in the opposite direction, with the speed pickup between the torque pickup and the pump coupling, the torque readings would be invalid, since the calibration curve of the torque tube is not symmetrical between normal and reverse loading. The output leads from the electrical resistence strain gauges and the toothed wheel are the leads mounted on the centre and gearbox end of the torque tube respectively. See Fig. 16

The readout system is situated at the main door end of the instrument bench, which lies along the left hand wall of the pump house. The main bank of instrumentation contains: an amplifying unit, the Vidar frequency converter, the torque readout and the speed readout in ascending order. To the left of the amplifier is situated the U.V. recorder.

The mode of operation of these units is described on the following pages.

4.2.3 Operation of equipment

(i) Observations before and after testing

Prior to, and immediately following each night's test run, certain observations are made.

The operator ensures that all the instrumentation is supplied from the mains and that all switches are in the 'on' position. The torque tube is uncoupled from the pump and the brushes are lowered into contact with the slip rings. A set of observations comprising bridge volts, standard cell volts, instrument zero and the readout from the torque tube under no-load conditions are taken. The brushes are then lifted.

With the tube still uncoupled from the pump, the pre-setting arm is bolted to the special collar mounted on the torque tube. This pre-setting arm applies a torque of 188 lb ft to the torque tube, and after attachment it is rotated until it lies in the horizontal plane. This is checked by the use of a spirit level fixed to the upper surface of the pre-setting arm. The brushes are again lowered and the same observations are made, the value of torque readout in this instance being that of a load of 188 lb ft applied to the tube.

The brushes are lifted, the pre-set arm removed, the brushes lowered and another set of observations, corresponding to those taken initially, are taken. In order to facilitate the operation, the circuits required to give these different observations are all wired to one switch which is mounted on the fron panel of the Vidar instrumentation.

On the completion of these observations, the operator informs the controller that he is ready for the commencement of the test.

(ii) Observations during testing

(a) <u>Start up observations</u>

The controller informs the operator prior to starting the main motor and the operator checks the following items.

1. Torque tube brushes lowered
2. U.V. recorder switched on
3. Connecting plugs between Vidar and U.V. Recorder in position
4. Amplifier gain set correctly
5. Readout switch set at NORMAL.

On completion of this check the controller is informed and the U.V. Recorder is set in operation. A recording is made throughout the time from starting the main motor until it attains the speed at which the test is to be carried out. The brushes are then lifted and the operator waits for the 'FLOW SET' indication.

(b) Test point observations

The operations carried out for taking observations for one test point are as follows.

1. On receipt of 'FLOW SET' indications from the controller, lower the torque tube brushes (Green light shows on brush lifting control box)

2. Set Vidar readout switch to NORMAL. Plug in U.V. Recorder leads. Check amplifier gain and take U.V. recording. Remove U.V. Recorder leads from Vidar and examine recording.

3. Set bridge volts switch to REVERSE and allow at least three counts to pass to remove the switching effect. Synchronise speed and torque counters. Note which RANGE of the Vidar is in use on data sheet.

4. With bridge volts switch in REVERSE position take two readings of torque and two readings of speed.

5. Give GREEN light to controller.

6. Set bridge volts switch to NORMAL and allow at least three counts to pass to remove the switching effect. Check synchronisation of counters.

7. After GREEN light (5 above) has been cancelled, and action 6 has been taken, give second GREEN light to controller.

8. Controller gives one ring (RED light). Take all speed and torque readings over the diversion period.

9. Set Vidar readout switch to 'B.VOLTS'. Set Vidar range switch to 1000. Let three counts pass to remove switching effect and with the bridge volts switch still in the NORMAL position note the value of bridge voltage.

10. Set Vidar readout switch to 'NORMAL'. Set Vidar range switch to the range used during the diversion period and set bridge volts switch to REVERSE. Check the synchronisation of the counters. Take two readings of torque and two of speed, after the switching effect has been removed.

11. Set bridge volts switch to NORMAL. Plug in U.V. Recorder plugs. Check amplifier gain and take U.V. recording. Remove the U.V. Recorder plus from the Vidar and examine recording.

12. Raise the torque tube brushes. (Red light displayed on brush lifting control box). This procedure is repeated for each test point.

(iii) Reasons for observations

(a) Pre-set observations of torque

Detailed investigations into the behaviour of the torque tubes disclosed a variability of the readout value when the tubes were under 'no load' conditions. This resulted in the use of the pre-set arm which enables a set value of torque to be obtained.

As has been described, two pre-set readings are taken and the mean of these is used in the calculation of torque.

(b) Normal and reverse readings of torque

The above investigations also revealed that a thermal e.m.f. was occurring at the slip rings on the torque tube due to a temperature rise at these points when the tube was being used under dynamic conditions. By reversing the bridge voltage and combining the values obtained with those taken with the bridge voltage in the normal positions this problem has been eliminated.

(c) Bridge voltage

The calculation of torque involves the use of millivolts per volt which is the same as output from torque tube (in mV)/bridge voltage (in V). [See Section 4.2.5]. The output from the torque tube is in millivolts before it is converted to cycles per second in the Vidar converter and to enable the calculation to be completed it is necessary to obtain the value of bridge voltage. The method of measuring bridge voltage is exactly the same as measuring the output from the torque tube.

(d) Standard cell voltage

In order to check the correct operation of the Vidar converter a standard cell is incorporated in the system. The standard cell produces a readout of 1.0196 ±0.0003 under normal circuit conditions. Any major change in this readout would indicate a fault in the Vidar circuit.

4.2.4 Calibration of equipment

Torque tubes will be statically calibrated in a special test rig before and after each series of tests and, if necessary, check calibrations will be made during the tests. Such work will usually be undertaken by the day shift, but must also be witnessed by the official observers, who must initial the calibration data sheets (Fig.20). The object of these calibrations will be to ensure that the value of C_L, which is the constant derived from such calibrations, is maintained within the accepted limits of accuracy. The readout counters are calibrated with the aid of a standard frequency receiver which is tuned to B.B.C. Droitwich.

4.2.5 Points to be particularly noted by observers during pump tests

1. The SPEED and TORQUE counters MUST be synchronised BEFORE making observations.

2. Careful watch must be maintained on the U.V. recordings to ensure that reading accuracy is maintained.

3. Brushes MUST be lifted on the completion of observations for EVERY test point.

4. A check on Standard Cell Voltage should be made periodically during a test run to ensure the correct operation of the Vidar converter.

5. Note the range on the Vidar converter. This can be switched to provide the readout of 10 000 on the millivolt display to correspond to either 5 mV, 10 mV, or 20 mV as required. The maximum reading corresponding to the safe working of the Vidar equipment on any one range is 11 000.

4.2.6 Calculation of torque

$$T = C_L \left\{ 0.5 \left[\frac{mV}{v} + \left(\frac{mVr}{V_r}\right) \left(\frac{N_1}{N_r}\right)^2 \right] - \frac{mVo}{V_o} \right\} + \quad 188 \text{ lb ft}$$

where N_r is the mean speed for the reverse readings

and N_1 is the mean speed for the normal readings

(see Appendix 5 for notation)

If the range used is other than 10 mV, the reading must be adjusted as follows.

(a) 5 mV range: divide reading by 2 to give equivalent mV on 10 mV range

(b) 20 mV range: multiply reading by 2 to give equivalent mV on 10 mV range.

The neon light beneath the visual display of numbers on the torque readout indicator signifies the number of seconds over which the count is made. In the case of the Bidders model tests a 10 second count will be taken and in this condition the decimal point will be in such a position as to give three significant decimal places. Therefore the maximum value which could be displayed would be 99.999.

4.3 Head measurements - Stations 3 and 4

It is possible to treat certain aspects of head measurement for both inlet and discharge together. In both cases, static pipe-wall pressure heads are measured, although on different types of instrument. It is assumed implicitly that there is a uniform pressure distribution across the pipe at the measuring station. Thus, the velocity head for these evaluation tests can be taken to be equal to that derived from the mean velocity, V, where

$$\bar{V} = \frac{Q}{A} = \frac{\text{flow in ft}^3/\text{s}}{\text{pipe cross section in ft}^2}$$

Thus velocity head $h_v = \bar{V}^2/2g$.

It is impossible to make an exact estimate of the error involved by making these assumptions without conducting lengthy traverses, but in the case of the Evaluation Tests it is probably very small(5).

It is important, however, to ensure that all four tappings at each measuring station do not register significantly different pressures. This can be checked as follows.

(i) By ensuring that the pipe wall is smooth in the vicinity of the tappings and that there are no burrs where the hole intersects the inner pipe wall. The pipes will be inspected, measured, and the surface roughness measured as soon as they are fabricated. As a result of criticism of the measuring pipes at the Observers Briefing Meeting, these pipes were honed and re-checked by NEL staff and the DMJM/MC representative. A separate report on this examination will be issued to all the Observers.

(ii) By ensuring concentricity and equality of bore with adjoining pipes. This is written into the manufacturing specification.

(iii) By comparing the readings given by each pressure tapping in turn for a given flow setting. During the evaluation tests, as soon as the flow is set, the difference between individual tappings at each station will be displayed on two manometer banks (Fig. 1b). Shortly prior to diversion of flow into the weightank, all the tappings at each station will be coupled together to measure head, provided no significant difference between tappings has been observed. Shortly after diversion, the difference between tappings will again be displayed until the end of the 'flow set' period. In the light of experience gained during the past eighteen months on the high power test rig, it is not expected that the difference between the individual tappings will be significant, provided items (i) and (ii) above are carefully observed. 'If the difference in the four readings observed in the suction pressure tappings exceeds 0.5 inch of mercury or in the discharge pressure tappings exceeds 1.0 inch of mercury or a sudden variation in differences is observed, an investigation to discover and correct the cause of the discrepancy shall be made. If the discrepancy is due to assymetry of flow created by the pump, the difference shall be recorded and the test be allowed to proceed, the four tappings being connected together to obtain an 'average' head reading.'

Another problem common to both inlet and discharge head arises as a result of the method of flow measurement. For any given constant combination of valve settings and pump speeds, the booster pumps together with the model pump have to overcome, in addition to a constant circuit resistance coefficient, a relatively small static head of the order of 10 feet, representing the height of the plane of aeration of the jet issuing from No 3 breakdown valve above the level of water in the sump. When the jet is directed from the sump into the weightank, the sump level falls, and therefore both model pump inlet and discharge heads undergo a similar drop. This is not large, because the area of the sump is large compared to that of the weightank. In theory, the flowrate should also fall, because the pumps have to overcome a larger head, but the head increment is so small by comparison with the total heads generated in the Evaluation Tests that the flow change can be neglected. The quantity most significantly affected from the point of view of model evaluation would be the NPSH, derived from the inlet head. Fig.22 shows the fall in the sump level due to filling the tank at various flowrates and for different diversion times. It will be seen that the fall will not be greater than 0.77 feet, nor less than 0.12 feet, and obviously, for cavitation tests especially, it is always preferable to keep the diversion time down towards the minimum of 30 seconds.

For normal performance tests at high NPSH values it is more important to ensure that Stations No 3 and 4 operators take a true mean of their manometer readings over the period of diversion than to keep to the bare minimum of diversion time consistent with accuracy. If these mean values of head over the diversion period are judged with reasonable skill, the effect on pump head will be completely negligible.

As will be explained below, different types of instruments are used for measuring head - mercury in water manometers for the relatively low pump suction pressures, and piston gauge manometers for the high discharge heads.

During the observers briefing meeting in April, 1967 both types of manometers were checked both against each other and independently against a precision deadweight tester with a National Physical Laboratory certificate (Fig. 23). The latter will be taken as the standard for all the tests. This cross-checking was made in addition to the normal running calibrations made during tests. Official observers must witness these checks and calibrations, and initial the appropriate data sheets.

4.3.1 Inlet head measurement - Station 3

This station is situated in the pump test house, and the operator, in addition to obtaining an eye-average of inlet static pipe-wall head on single limb mercury-water manometers in series during the time of diversion, must also note the corresponding reading on a wall mounted Bourden gauge, the pump inlet water temperature as displayed on the chart recorder by the control panel, and the barometric pressure on the Fortin barometer by the Bourden gauge. These further readings should be taken either immediately before or immediately after the diversion period. Their rate of change with time, if any, will be relatively small. A specimen data sheet for Station 3 is given in Figs 24 and 25 and calibration sheet in Fig. 26.

(a) Use of single limb manometers

The single limb mercury-in-water manometers used are of NEL design Fig. 27. They are robust and simple, 80 inches scale length, subdivided in inches and tenths of one inch. At the base is a large area flat mercury reservoir, (Fig.28) to the top of which the high pressure water from the measuring station is applied. Dipping below the surface of the mercury and passing through a seal in the top cover plate, is the 80 inch Perspex manometer tube. The pressure of the water on top of the mercury forces the mercury up the tube. The tube is supported and protected by vertical steel columns made of standard channel, with a shaped wooden backing piece which holds the tube against the gap between the inward facing channel sections. The wood also provides a light coloured background against which to see the level in the tube. At the top of the manometer, the vertical channel columns are joined by a flat plate, on which is welded a steel boss. The lower part of this hollow boss contains the upper seal for the perspex tube. Above this a cock is fitted for venting. A second connection leads to a mercury trap, fitted in case too much pressure is accidentally applied, causing the mercury column to rise more than 80 inches. From the mercury trap, a lead is taken to a large flat tray horizontally mounted so that the overflow level in the tray corresponds exactly to the pump centreline level, which is taken as datum. The tray is therefore referred to as the datum tray.

The high pressure lead to the manometer base is taken via a block mounted on the side of the manometer. The low pressure lead from the mercury trap at the top of the manometer is taken to the datum tray via the same block. Separate cocks, one for shutting off the high pressure lead, and one for shutting off the low pressure lead, are mounted in the block. A third cock at the block opens a bypass line between the high pressure and low pressure sides of the manometer. This last cock is most important to the successful functioning of the manometer. Firstly it must be complete leakproof, or the manometer will give a false reading. Secondly, when it is opened, the high pressure water flows to the low pressure side of the manometer, and, if all the cocks are open, finally arrives at the datum tray causing it to overflow, thus purging the manometer connecting lines and maintaining the datum tray level. Thirdly, opening the bypass valve tends to equalise the pressures and zero the manometer.

Important precautions have to be taken, however, before reading manometer zeros. It must be remembered that the purging action acts only in respect of the external leads coming away from the block to the pump and datum tray. Internal purging of air can be effected by either or both of two methods. The bypass valve may be opened and closed intermittently which has a pumping effect, and, in addition, the air bleed valve at the top of the manometer may be opened until running full of water. It has been found in practice that once this initial purging is effected, and the system is full of water, there is seldom any tendency for further air to collect within the manometer, and it is sufficient to keep the external leads purged. The act of opening the bypass draws down the mercury column and with it the internal water, together with any air, into the Perspex tube, where it is immediately detected. Having assured complete purging of air, it is absolutely essential to close off the high pressure (and preferably the low pressure) valves to the manometer, leaving the bypass open. Only then will the manometer register its true zero. If the other cocks are left open, the manometer will register a small but significant differential due to the head loss of the water flowing through the bypass line from the high to the low pressure side. Observers must check zeros independently and initial values entered in single limb manometer calibration sheets (Fig. 26).

For strength and simplicity the mercury column rises from the centre of the base. This means that the actual mercury level when pressures are equalized, is out of sight in the reservoir, with a thin layer of water above (it would obviously be unwise to fill the reservoir completely with mercury). There is therefore a Perspex cylindrical float, scribed with a datum line near the top, floating on the mercury column. The float is of sufficient length for a scale reading to be obtained when the pressures are equalized. This scale reading is the manometer zero. All readings are taken with reference to the line scribed on the Perspex float. It is a common mistake for the uninitiated, when using this apparatus, to read the mercury level instead of the float level as indicated by the line. Because the line completely circumscribes the cylindrical float, it is easy to avoid parallax errors in reading. The float is an easy sliding fit inside the tube, but not so loose that it does not float vertically. There is therefore the danger that if the manometer becomes contaminated with particules of dirt, the float may jam. Any tendency to do so will be most apparent when the bypass valve is opened or closed, causing rapid level changes in normal operation; mercury seen up the side of the float is an indication of jamming.

The manometer will be purged during the 'FLOW CHANGE' phases by opening the bypass valve. During the 'FLOW SET' phases the bypass valve will be kept closed.

It will often be impossible to measure the inlet head on one 80 inch single limb manometer for the high NPSH values required for the Evaluation Tests.

Two or more manometers may then be connected in series, the low pressure lead from the first manometer going to the high pressure side of the second manometer, and so on; the low pressure lead on the last manometer then connects to the datum tray. With such an arrangement, it is important to open all the bypass valves before applying pressure to the manometer bank. With these valves open, however, all levels will be substantially zero, and may be brought up gradually together to obtain approximately the same level throughout the bank by judicious manipulation of the bypass valves (e.g. if one level is higher than the rest, and the bypass on the high level manometer is cracked gently open, its level will fall, and the others rise to compensate.)

It is permissible to take one or more of a series of such manometers out of the test simply by opening its bypass valve and then ignoring it. Since the other manometer bypasses are closed, there will be no throughflow, and the bypassed manometer will therefore register its zero.

The derivation of the manometer coefficients is given below.

The height of mercury H_m in inches is converted to feet of water at the specific gravity and temperature of the manometer as follows

(a) Subtract zero reading (Fig. 26) from H_m to obtain corrected mercury column height H_{mc}

(b) Multiply H_{mc} by

$$K_{area} \times \bar{\rho}_m = K_{area} \times \frac{\rho'_{Hg} - (s.g.)_{water}\,\rho_w'}{12.\ (s.g.)_{water}\rho_{w'}}$$

where K_{area} allows for the ratio of the areas of the large base and the manometer tube (see values of constants given in Appendix 1).

ρ_{Hg}' is the density of mercury at the manometer temperature θ'.

$(s.g.)_{water}$ is the specific gravity of the sump water related to distilled water.

ρ_w' is the density of distilled water at the temperature θ'

12 converts from inches to feet.

For example,

at 18°C ρ_{Hg} = 13.5512 x 62.428 lb/ft^3

$(s.g.)_{water}$ taken as 1.0020

ρ_w' = 62.342 lb/ft^3

$$\bar{\rho}_{m_{18°C}} = \frac{13.5512 \times 62.428 - 1.0020 \times 62.342}{12 \times 1.0020 \times 62.342}$$

$$= \frac{845.974 - 62.467}{12 \times 62.467} = \frac{783.507}{749.604} = 1.0452$$

To convert to feet of water at the temperature of the water being pumped (that is H_1, H_2, H_3 in Appendix 1) the corrected height of the mercury column is multiplied by

$$K \text{ area} \times \frac{\bar{\rho}_m}{\rho_p}$$

where ρ_p is the mass density of water being pumped.

Slightly different dimensions have been used in the manufacture of these NEL single limb manometers and as a result the area ratios between the bases and the tubes are different, as shown in Appendix 1.

For No 1 Manometer where the area correction factor is 1.00209 if the temperature is 18°C and the sump water specific gravity is taken to be 1.0020, then the manometer multiplier will be 1.0474.

For No 2 Manometer where the area correction factor is 1.00227 if the temperature is 18°C then the manometer multiplier will be 1.0476 and for No 3 the figures are 1.00230 and 1.0476.

Fig. 27 shows a photograph of a single limb manometer. In April 1967, the manometers were emptied, cleaned, and refilled with distilled mercury.

The area ratios given above and in Appendix 1 were calculated during April 1967 by direct measurement of the fall in level of mercury in the base for a given rise in the Perspex tube. Special transparent sight blocks were fitted to the manometers for this purpose. A specimen calibration sheet is given in Fig. 26 and these tests were demonstrated to the official observers.

(b) Use of U-tube manometers

For low and subatmospheric heads single limb manometers cannot be used conveniently, and should the need arise during the Evaluation Tests, a changeover will be made during a cavitation test from these manometers to a simple U-tube instrument. In such cases an overlap will be arranged to check one instrument against the other.

(c) Use of Bourdon pressure gauges

The Bourdon pressure gauge is used only for monitoring purposes, for example to indicate to the operator how many single limb manometers will need to be used. Its reading will be recorded on the data sheet to check for gross reading mistakes, but on no account will the Bourdon gauge reading be used in the evaluation data. It will be calibrated in April 1967, and later in October, but not between tests, since it is used in parallel with the mercury manometers and this constitutes a continuous running calibration.

A Fortin barometer, with a 1967 NPL calibration certificate (National Physical Laboratory) will be installed in the pump test house for the Evaluation Tests. This will obviate the need to apply corrections to the reading of the barometer in the Reynolds building which is on the 33 ft level floor. Moreover, there can be a measurablo drop in pressure in the pump test house when the rig is running with the doors closed, due to the action of the cooling fans for the windings of the main motor. This makes precise corrections from the 33 ft level barometer almost impossible to apply. The barometer installed at the point of measurement will remove such uncertainties.

4.3.2 Discharge head measurement - Station 4

The high heads to be developed by the bidders models in the forthcoming evaluation tests preclude the use of mercury/water manometers for discharge head measurements because

(i) if a single U-tube were used its height would be about 175 feet

(ii) if standard NEL 80-inch single limb manometers were used in series, the number required would be such that the accuracy of readings would be impared, since it would be impracticable to apply an averaging method to the height of each mercury column over the test period.

The fundamental standard of pressure measurement for pressures higher than those for which a liquid column can be conveniently used is the deadweight free piston gauge, where the pressure to be measured is balanced with a piston, of known area, loaded with weights and working in a closely fitting vertical cylinder.

The NEL piston gauge manometer[6] (Fig 29) is basically such a device incorporating a liquid manometer to measure small variations or increments of hydraulic pressure. The principle involved is illustrated in Fig. 30 whilst Fig. 31 is a cross-sectional elevation of the instrument. The hydraulic pressure is transmitted, through a water/oil interface level with the pump centreline, to the underside of the piston causing an upward thrust to the piston/carrier assembly and displacement of the distilled water in the container. This upward force on the piston is balanced by the weight of the piston/carrier assembly, by weights added by the operator to the carrier and by the height of the distilled water column.

Two methods of operation may be employed:

(i) the distance that the piston has moved from its calibrated position can be read on the manometer vernier scale and this reading incorporated in the head equation obtained from calibration, or

(ii) weights can be added to the carrier to return the piston to its calibrated position, thus giving the same 'null' reading on the manometer vernier scale for each test point.

For the Evaluation Tests it is intended to use method (ii) because operation of the manometer is facilitated and the calculation of the head results is simplified. A specimen data sheet is given in Fig.32.

Before each test series, the piston gauge manometer is calibrated against a free piston deadweight tester, sufficient calibration points being taken to ensure that the expected pressure range of the tests is covered. Calibrations must be witnessed and data sheets, Fig. 33, initialled by official observers.

Friction error between the piston and cylinder is minimized by rotating the piston to provide a contiguous oil film between working surfaces. The oil chosen for the instrument, Tellus 27, has a viscosity which is almost constant over the temperature range encountered.

(a) Head equation for piston gauge manometer

The constants in the head equation for the piston gauge manometer can be determined from the physical dimensions of the instrument and in the past these have been used in combination with a nightly cross-calibration against a deadweight tester to measure discharge heads. A direct calibration procedure against the deadweight tester to establish the full equation has the advantages of simplicity and correlates all results against the one standard.

Thus,

$$\text{Discharge pressure head, } H_d = \frac{144}{\gamma_p}\left\{K\,W_2 + C\right\} \text{ ft } H_2O$$

when the manometer on the instrument is reading at the null point of 'h_m' inches. The notation is given in Appendix 5. The calibration sheet for the piston gauge manometer is given in Fig. 33.

(b) Calibration procedure and use of constants

Prior to each night's pump testing the expected range of discharge pressures will be estimated, and at least ten equally spaced values spanning this range will be chosen as calibration points. The standard procedure to be used is as follows. For each calibration point the required pressure is obtained by placing the appropriate weights on the Budenberg Deadweight Pressure Tester (Serial No 3557), raising its free piston by means of the screwed plunger and rotating the weights and piston to minimize the effects of friction. A number of weights estimated to balance this pressure are placed on the weight carrier of the piston gauge manometer, and with the motor switched on and the piston rotating, the valve from the deadweight tester is opened and pressure applied to the piston. Small weight adjustments are made until a balance is attained. This is shown when,

(i) the deadweight tester piston is raised and the head is floating, clear of the stops, with the weights rotating, and

(ii) the piston gauge manometer is floating in its mid-position, which can be readily determined by moving the piston assembly up and down by hand. This mid-position determines the position of 'h' - the reading on the water manometer vernier scale.

For the first calibration point, a few minutes are allowed for trapped air to leak out past the labyrinth seal and for the small oil leakage at the lower end of the piston to be deflected by the oil spreader.

The procedure is then repeated for each of the remaining pressure points in the range and the values of W noted for each pressure.

Because the deadweight tester and both piston gauge manometers (60 to 500 and 500 to 1500 lbf/in^2) are positioned so that the level of pressure application for each is on the pump centreline, no height corrections are required in the discharge head calculations.

Provided the quantity of distilled water used in the manometer is maintained constant within adequate tolerances, and the instrument suffers no permanent deformation or damage, the values of C and K should not vary from day to day.

The main purpose of the daily calibration during tests is to ensure that these values do remain substantially constant, and to investigate the cause of any significant changes that might be noted. Fig. 33 shows the calibration sheet. The first two columns show the pressure applied by the deadweight tester being used as the calibration standard (Fig. 23) and the counter-balancing weight applied to the piston gauge manometer. At the foot of the sheet are the values of K and C to be used in the calculation of pump discharge head. These will be entered as raw data into the computer with the other constants under the headings K and C in the computer print-out shown in Appendix 6. The third column on the calibration data sheet lists values of KW + C; these are the values of pressure which would be calculated from the weight applied to the manometer using the values of K and C shown. The last column lists the percentage deviation of this calculated pressure from the pressure applied by the deadweight tester.

There are thus two checks to be made:

(a) Comparison of K and C values with previous sheets

(b) Examination of the values of the deviations.

During the fortnight previous to the installation of the first Bidders Model, a number of calibrations of the piston gauge manometer will be made by NEL to provide a backlog for the above assessments.

(c) Points to be especially noted by observers

(i) When watching a calibration:

1. The piston gauge manometer must be levelled by means of adjusting screws and spirit level.

2. The pressure line between the deadweight tester and piston gauge manometer must be free of air bubbles.

3. There must be no oil leakage from the pressure line or screwed connections, and only minimal leakage past the piston glands. The small leakage at the lower end is deflected, by the oil spreader, into the leakage container and this must not be full of oil.

4. The water manometer must be free of air bubbles.

5. The inside of the leakage container must be free of foreign matter.

6. All weights and the weight carrier must be clean and dry.

7. The free piston in the deadweight tester must be at the correct level, and rotated with the weights used, during calibration, to minimize friction.

8. Before calibration, the piston gauge manometer must be operated, under pressure, until the angled spreader on the lower piston begins to throw oil on to the inside wall of the leakage container.

9. Sufficient calibrations must be taken to span the expected pressure range of the tests for each night.

10. A double check should be made on the weights used, i.e. they should be totalled before removal from the carrier and against the empty spaces in the storage boxes.

11. The piston level must be the same for successive calibrations. This level can be noted by observing the water manometer vernier scale.

(ii) When observing measurements of discharge head:

1. Pressure lines from all tapping points must be vented and free from air.

2. There must be no water or oil leakage from the pressure lines or screwed connections.

3. The oil leakage container must not be full.
4. The water manometer must be free of air bubbles.

5. The inside of the container must be free of foreign matter.

6. All weights and the weight carrier must be clean and dry.

7. All appropriate valves and cocks must be fully open during readings.

8. The piston gauge manometer must be level.

9. A double check should be made on the weights used, i.e. they should be totalled before removal from the carrier and against the empty spaces in the storage boxes.

10. The water level in the manometer tube must be the same for all test readings associated with a particular calibration.

Note:

<u>On the 60 to 500 lbf/in^2 range:</u>

A weight increment of 0.01 lb	0.115 ftH_2O (pressure head)	approx.
0.01 inch on manometer scale	0.049 ftH_2O (pressure head)	

<u>On the 500 to 1500 lbf/in^2 range:</u>

A weight increment of 0.01 lb	0.359 ftH_2O (pressure head)	approx.
0.01 inch on manometer scale	0.153 ftH_2O (pressure head)	

A specimen data sheet for recording discharge head measurement is shown in Fig.

4.4 Flow measurement - Station 5

4.4.1 Description of equipment

The determination of the absolute flowrate for all tests carried out using the main water test facilities in the Reynolds building is based on a 30-ton weightank and diverter system[7]. The weightank and diverter are located at the far end of the main test bay (Fig. 34a and b).

Under normal flow conditions the water entering the diverter fishtail is deflected to the sump by means of the diverter plate which is activated by an electric motor. During flow diversion periods the water entering the diverter is deflected to the weightank. Control of the flow entering the diverter system is achieved by means of a motorized variable opening spear valve (Valve No 3) situated upstream of the diverter fishtail. A pressure gauge calibrated in lb/in^2 is located near the cascade elbow and this indicates spear valve pressure upstream of the valve. An air bleed line is incorporated upstream of the spear valve.

An air vent is provided just downstream of the spear valve control orifice to overcome any instability of flow at the point where the nozzle changes from the running free to the running full condition (Fig. 35).

The 30-ton weightank is suspended in a pit by means of a weighbridge. A small electrically driven scavenge pump automatically removes water from the pit. The weightank is emptied by a centrifugal pump which cuts out automatically when the weightank has been emptied. This pump transfers the water from the weightank back to the sump. It can come into action only when a sliding length of pipe on the suction side connected to the weightank is lifted by an air piston to seal to the pump suction. When the pump is not operating there is thus no transfer of weight between pump and weightank. Damage to the weightank mountings during emptying and diversion periods is prevented by means of pneumatic buffers.

The weighbridge has a steelyard beam with three poises covering graduations of thousands, hundreds and tens of pounds.

Adjacent to the weightank is a combined control and instrument console (Fig. 36a). This console incorporates control buttons for the spear valve, two service pumps and diverter. Dials on this console indicate service pump speeds and spear valve position. Two lights on the console indicate when the flow is normal or diverted; the green light shows that the flow is normal and being deflected to the sump, while the red light shows that it is being diverted to the weightank. The console also contains two Hewlett Packard electronic timers which are used to measure the diversion time. The diverter is linked to a photo-electric cell switch which activates the electronic timers when the diverter plates kick over to the flow diversion position. At the end of a diversion period, pressure on the normal button causes the diverter plate to return to the normal flow position and stop the timers.

To the right of the control and instrument console stands another cabinet containing the electromagnetic flowmeter and line temperature readout instruments (Fig. 36b). The line temperature is measured by a thermometer.

placed downstream of the electromagnetic flowmeter but the latter will not be used during the Evaluation Tests since the temperature which enters into the calculations of the volume flowrate through the pump is the temperature of the water at the model pump itself. Both instruments produce a rectilinear trace on recording paper as well as having a scale from which direct and instantaneous readings can be noted. Since the speed of the recording paper feed spools can be set, it is possible to check back and verify how one or other varied during a particular diversion period. The electromagnetic flowmeter readout is utilized solely for setting up flows and monitoring purposes and on no account will the E/M flowmeter readings be used in the evaluation of tests. The E/M flowmeter has a calibrated range of from zero to 25 cusec.

A thermometer is located on the far wall of the Main Test Bay in the Reynolds building adjacent to the diverter assembly. This wamples water from the pipe just upstream of the spear valve and discharges the water back to the sump. This bypass must be closed during all diversion periods. Since this thermometer will not read during the Evaluation Tests it may be ignored except that it must be ensured that it is bled of air.

In the Evaluation Tests the actual measurements obtained at the weightank can be used to give the mass flowrate which takes into account the bouyancy correction factor. As stated earlier, the volume flowrate is a function of water temperature at the test pump and specific gravity of the water being pumped.

Near the Valve No 3 pressure gauge a board is located containing four coloured light bulbs. The lights indicate the position of the water level in the constant head tank relative to the normal constant head level. The normal level is indicated by a green light. To the left of it is a white light which shows if the level drops more than $\frac{1}{8}$ inch below normal. Above all three lights is a red light which would come into operation tripping out all pumps and stopping the tests to prevent the Laboratory from flooding in the unlikely event of the level in the tank rising unobserved and unchecked. The constant head tank is isolated from the circuit, and any change in lights during tests would indicate leakage past the isolating valves.

4.4.2 Setting up procedure

1. Switch on the mimic-diagram (control room). This mimic diagram covers only the part of the high power pump test rig which was already in the Reynolds building in 1964. It is used normally for flow calibration work and is only referred to here for completeness.

2. To the right and above the mimic-diagram the flow transmitter box is located. Open box and check that flow range card for electromagnetic flowmeter is the correct one. (Three cards are available, one marked 0 — 2.5 cusecs another marked 0 — 10 cusecs and the last card marked 0 — 25 cusecs). In the case of the Evaluation Tests the 0 — 25 cusec card should be installed. Check that the main switch is on at the flow transmitter box.

3. Check that switch for the motorized valve No 91 is on to complete circuit for electromagnetic flowtube. Valve No 91 (Fig 10) is located in basement downstream of electromagnetic flowmeter.

4. Check that a supply of compressed air is available to divert switch mechanism.

5. Plug in electrical lead for photo-electric diverter switch. This lead goes to the Astral cabinet, 28 d.c. socket, located above the main venturi pit. Switch on photo-electric light beam switch located to the left and below electronic timers. On diverter panel position diverter and counter switches to 'main'.

6. Make connection to mains socket on wall near the weightank for electronic timers, line temperature readout and electro magnetic flowmeter readout. A single lead serves all these instruments. Check that the individual mains switch for each instrument is on, in addition check that the driving motor for the recording paper feed drum is switched on.

7. Test procedure for checking electronic timers:

(i) Move gate switch (at rear of each unit) to internal operation position. This means moving the switch toggle from the left hand position (external position) to the right hand position (internal position)

(ii) With display switch in hold position and sensitivity control in check position operate function switch through its various positions and note that display is correct for each of the selected positions.

(iii) Switch gate switch to external position.

(iv) Switch function switch to correct position to give correct position for decimal point on display. Decimal point positioned to give three places before decimal point on upper electronic time and two places before decimal point on lower electronic timer.

(v) Press reset button on each timer to give zero display.

(vi) The following check also serves to ensure that the diverter switch and autotimer are functioning properly. Switch autotimer on and set to 30 seconds. Press diverter button and hold pressure on button for a few seconds (this operation cancels green (normal) light and brings on divert (red) light). At the end of approximately 30 seconds the autotimer mechanism returns the diverter to its normal position and the lights change back from red to green. The electronic timer discharge should then be checked, and may be expected to read 31 to 32 seconds, rather more than the auto-timer setting (which will automatically return to its present position after actuating the diverter to normal) owing to the lag between the time of energising the circuit and the time at which the diverter plate passes through the fishtail jet.

(vii) Press reset buttons on each timor to give zero display

(viii) Switch off auto-timer and repeat the above sequence manually, this time allowing the 'divert' period to last for approximately 100 seconds before pressing down for a few seconds on the 'normal' button. Check that the time indicated on each electronic timer display panel matches.

(ix) Push reset buttons on each timer to give zero display.

(x) If circumstances prevent actual movement of diverter plate to the diversion position the same effect can be achieved by pushing reset buttons on electronic timers and switching the photo-electric light beam switch to off and after allowing 100 seconds to elapse switch to on again and repeat check described in 6 above.

(xi) Switch on autotimer and check that it is set for 30 seconds.

8. Check that water level in sump is not less than 4 ft 6 inches. If sump level is not sufficient add make-up water either from constant head tank or from pond. A note must be made if the sump has to be topped up, especially if the supply source is the pond. The importance of this lies in the fact that the 'S' factor in the calculation of volume flowrate is dependent on the specific gravity of the water being pumped. In the case of the Evaluation Tests the specific gravity is determined during the day for the evening test runs and if water has to be added to the sump then the specific gravity will be determined early the following morning in order that the correct value can be used in the computations, Fig 38

9. Check flow circuit and open or close valves in circuit where necessary. Ensure that all other circuits are isolated from pump test flow circuit. Open bleed valves on top of re-absorber and vent any air present to atmosphere close re-absorber bleed valves. Switch on service pump isolaters.

10. Prime emptying pump for weightank and ensure that after priming the valve is closed. Leakage of water from the telescopic gland usually occurs for some time after priming the pump. The quickest method of stopping this is to divert water to the weightank after flow has been established and half fill the tank. Empty the weightank and establish that emptying pump is operating satisfactorily. When weightank has been emptied a check of leakage through the telescopic gland should be negative.

11. Open air bleed upstream of spear valve.

12. Check that air vent to diverter system upstream of fishtail is clear.

13. Press No 3 valve open button and allow No 3 valve to reach fully open position (consult spear valve position gauge) in order to drain off any water present in the overhead pipe leading to the diverter system. Once the booster pumps have been started and the necessary control valves of the spear valve opened, any water coming through Valve No 3 must then have been newly pumped from the sump via the test circuit. Failure to drain the overhead line beforehand could cause a delay of several minutes in detecting absence of flow through the system as a result of one of the isolating valves in the line still being closed.

14. Check communication system by calling test controller in pump house. Inform test controller of situation as regards instruments, auxiliary equipment, sump level and other relevant details.

15. Prepare data sheets, a specimen of which is shown in Fig. 39 for use during tests on both the electromagnetic flowmeter and temperature recording charts mark pump being tested, date and other relevant identifying data.

16. Stand by for call from test controller to establish flow.

17. On order from the test controller start up No 1 booster pump or No 1 and No 2 booster pumps. Open pump valves (valve immediately upstream of booster pump may require opening) or see that this is done by an assistant. On order from controller raise service pump speed to required level. If both service pumps are used the speeds should be brought up in unison. As soon as water starts to flow from fishtail notify controller.

18. Stand by headphones for further instructions.

4.4.3 Test procedure

1. <u>Starting up procedure</u>

(i) Adjust spear valve positions to give gauge reading of 6 to 7 inches opening

(ii) Check air bleed is open

(iii) Stand by for notification of starting up by controller

(iv) During starting up keep a check on booster pump speed, pressure upstream of diverter and electromagnetic flowmeter readout.

2. <u>Test operational sequence</u>

(i) On completion of starting procedure, weighbridge operator, in conjunction with controller, adjusts No 3 valve opening and service pump speed(s) to give the required flow as indicated by electromagnetic flowmeter readout. Check must be kept on pressure gauge at No 3 valve to maintain pressure at 10 to 15 lb/in^2 by manipulation of No 3 valve. When flowrate has been set bleed off air at both air bleed and wall thermometer. During the air bleeding period balance weigh-tank steelyard beam by manipulation of poises. When air bleeding has been completed notify controller. Stand by headset.

(ii) Note speeds of No 1 and 2 pumps, spear valve pressure and setting and electromagnetic flowmeter reading on separate control and checking sheet from test data sheet. Make preliminary weighing of empty tank. Notify 'READY' (green light).

(iii) On order from controller, accompanied by change of signal,light from green to red, make final balance and check of steelyard, and record weight on both data sheet and checking sheet. Data collector must check that weight has been correctly recorded. Press reset button on each electronic timer, and give controller green light.

(iv) On order from controller to divert, press (and hold for a few seconds) the divert button and notify controller when diverter plate kicks over to the diversion position. During the nominal 30 second autotimer controller diversion period, (which will not be less than 30 seconds or 10 000 lb of water) check and note Nos 1/2 booster pump speed(s), spear valve pressure and electromagnetic flowmeter reading. Report to controller any unusual or alarming changes in instrument readings, diverter action etc. Towards the end of the diversion period, using the autotimer clock, give to controller a countdown of the seconds before diversion ends. Note controller gives weighbridge operator a red light as soon as diversion commences.

(v) Immediately after the diversion period has ended weigh the weightank, leaving poises in position until independently checked by data collector, and note this together with the temperature of water at the pump (this is given by the controller) and the specific gravity of the water being pumped and the diversion time. It is important that the weightank operator should start emptying the weightank immediately after obtaining the weightank reading after the diversion period since this operation takes about 3 minutes to complete. As soon as this reading is obtained and the data sheet completed the operator will calculate the flow on his checking sheet, using a desk calculating machine. He may be interrupted in this to assist in changing the flow, returning to part (i) of sequence, but he must not re-enter part (ii) of sequence until flowrate has been calculated and data sheet initialled by data collector. This sequence recycles for each set of test observations. At suitable times check system for air by opening bleed points upstream of No 3 valve and at re-absorber.

Closing down procedure

(i) Controller notifies weightank operator shortly before and immediately after the main motor is switched off.

(ii) In co-operation with controller the No 1, (2) pump speed(s) is reduced to the minimum speed(s) and No 3 valve opening reduced. The operator must keep a check that No 3 valve does not close too quickly, giving rise to excessive upstream pressure.

(iii) At a certain point in the closing down procedure the controller will himself trip at No 3 booster if necessary, and then notify operator to shut No 3 valve completely since it is advisable to try and retain some pressure upstream of No 3 valve (10 to 15 lb/in^2).

(iv) On notification from the controller that all valves are shut the weighbridge operator closes the Nos 1 and 2 pump discharge valves and then shuts off the booster pump motors. Note that in the case where the shut-down is only for a short period Nos 1 and 2 boosters may be allowed to continue running at rolling speed(s).

4.4.4 Calibration

The weighbridge has been calibrated by means of deadweight and water weight calibrations to give an estimated accuracy of ±0.1 per cent[7].

The electronic timers are checked against radio signals from the B.B.C. station at Droitwich and are accurate to one part in 10^5.

The overall accuracy of the system has been assessed including random and systematic uncertainties to be within a tolerance band of ±0.15 per cent, with statistical 95 per cent confidence limits.

4.4.5 Method of measurement of the flowrate

The flow is set up and allowed a few minutes to settle. The steelyard beam is balanced and the initial weight of tank and water noted. The electronic timers are set at zero. The 'divert button' is then pressed and hold for a moment until the diverter swings over to the divert position. After a suitable time the normal button is pressed and the steelyard beam again balanced and the final weight of tank and water noted. The water temperature at the pump and diversion time are also noted. The diversion time is usually between 30 seconds (minimum) and 50 seconds, and the minimum weight of water is 10 000 lb. The specific gravity of the water used is checked daily and noted.

In sample form the flowrate may be expressed by the equation

$$Q = \frac{W'}{t} \times \frac{1}{\gamma_p}$$

where Q is in cubic feet per second, W is the weight difference between the measurements before and after diversion (lb), t the time of diversion (seconds) and γ_p the fluid specific weight at the temperature of the test (lb/ft^3). In practice, it has been found convenient to measure specific gravity (s.g) of the water in the system and to obtain the sp.wt. by reference to the sp.wt. of distilled water (γ_p^1) at the same temperature as the water in the test line.

$$\gamma_p = (s.g)\,\gamma'_p$$

An air buoyancy correction factor is also introduced to allow for the fact that water is buoyed up by the atmosphere to a greater extent than the brass weights which are the ultimate standard against which the weighbridge is checked.

The equation therefore becomes $Q = \frac{W}{t} \times s$ where s is a correction factor taken from tables(6), reproduced in Table 10.

A specimen data sheet for flow measurement is shown in Fig 39.

4.4.6 Possible sources of faults

1. Air in circuit

2. Air bleed left open allowing water to escape to sump during diversion period.

3. Failing to check that weightank steelyard is balanced just before diversion commences. If leakage occurs into weightank and a substantial time has elapsed between balancing the steelyard and diverting the flow this results in a lower mass flow being measured.

4. Leakage through flanges etc. in pipe circuit

5. Leakage via wall thermometer via bypass

6. Weightank rubbing on 'supports'.

7. Total or partial loss of compressed air to diverter switch mechanism resulting in some water being diverted to weightank and some to the sump during the diversion period.

8. One electronic timer giving a slightly different reading from the other due to a fault in one or other or both.

9. Pit scavenge pump allows build up of water in pit.

10. Air vent to diverter system upstream of fishtail is totally obstructed causing instability in flow emerging from the control orifice into the fishtail (ref. 2).

4.4.7 Potential troubles which may occur during setting up or pump testing procedure.

All faults should be reported immediately to the controller who will decide what actiontto take, and record the incident on the control sheet.

(i) Loss of compressed air supply to diverter plate switch. This results in the diverter plate being kicked over from the normal position to the divert position. Pressing the normal button brings the plate back to the normal flow position. However, the plate returns to the divert position as soon as pressure on the normal button is removed. The emergency procedure in the event of this happening is to keep a constant pressure on the normal button and inform controller and await rectification of fault.

(ii) Weightank emptying pump fails to cut out when weightank is empty. Resort to manual cut out until such time as cut out mechanism is examined and rectified.

(iii) One electronic timer fails to give same diversion time as other. Note both diversion times and have fault rectified by electronics department.

4.5 Data collection

Data collection is the responsibility of one member of the NEL team. He must visit each measuring station in turn, make on-the-spot checks for obvious errors or omissions and bring the sheets to the data checking station, situated alongside the control panel, at the place where the multi-tube pressure tap comparison manometers are mounted.

At this station, three large scale graphs, covered with washable transparent sheet, are laid. These graphs will be used to check the data from stations 2, 3 and 4 as follows.

Station 2

The average 'normal' and 'reverse' mV readings from the torque tube will be plotted against the reading from the wattmeter indicating power input to the 4000 hp motor.

Station 3

The total height corrected for zeros measured in inches of mercury will be plotted against the suction Bourdon gauge reading.

Station 4

The total weight added to the piston gauge manometer will be plotted against the discharge Bourdon gauge reading.

At Station 5, the flow as obtained from the weightank in ft^3/s will be calculated by desk machine. This flow will be entered on a checking sheet separate from the official test data sheet, together with the flow reading from the electromagnetic flowmeter. Thus, because the flowrate is calculated at Station 5 for each test point, the data collected from this station is one point behind that from the other stations.

The sequence ofoperation for checking will be as follows.

1. Flow set. Collector at Station 5. Checks that empty tank weight is correctly entered.

2. Divert. Collector waits until full tank is weighed, checks that final weight and time of diversion are correctly entered, leaves data sheet with Station 5 operator.

3. Collector goes directly to Station 3. At the end of diversion, Station 3 operator has closed valve in pressure tapping line, leaving mercury columns 'locked in' at height showing at that time. Collector checks locked in heights against heights entered on data sheet, and that zero correctionshave been properly applied. Takes Station 3 data sheet.

4. Collector goes to Station 4. The operator here must leave weights untouched until collector has checked them against weight recorded on data sheet. Collector then takes Station 4 data sheet.

5. Collector goes to Station 2. Checks that bridge volts and zeros are normal and that the difference between 'normal' and 'reverse' readings appears consistent. Takes data sheet.

6. Collector checks data sheets from Stations 2, 3 and 4 at checking centre, and initials if satisfactory, in conjunction with official observers.

7. Reports to test controller if test satisfactory or not. If not, must inform Chief of Tests.

8. Collector returns to Station 5, and examines checking sheet to confirm that flow calculated from the weightank readings is consistent with that from the electromagnetic meter. Initial if satisfactory.

4.6 Data checking and storage

Data sheets are kept at checking centre until all observers have initialled, after which they are taken to card-punching room. Checking of card punching is an internal NEL matter, since data input to computer is included with the print-out of processed results. Checking by observers is dealt with in Section 8. The control data sheet remains at Station 1 until the end of the night's test run. It is then taken by the collector to the NEL safe for storage.

4.7 Photography - Station 7

The steps to be taken to ensure water clear enough to make visual observations have been given under 3.1.14. The degree of success of photography cannot, however, be planned with the same certainty as that of the other observations. Air coming out of solution, pump geometry and consequent lighting difficulties are factors which cannot be foreseen long in advance. The former factor will probably be resolved during the trial tests in February/March 1967, but the latter must await the arrival of the individual pumps.

Preliminary studies will be made to explore the lighting possibilities by the use of still photographs taken during the daytime before the start of the tests proper, so that actual testing time will not be wasted. Final setting up will be done during commissioning tests, so that equipment will be ready for the manufacturers and official tests.

At the Observers Briefing Meeting it was agreed that while as many photographs as possible would be taken, visual study of cavitation patterns was still the most satisfactory method since the eye could detect the extent, shape and character of the bubbles better. Sketches of what could be seen would be drawn and agreed by NEL, DMJM/MC and the manufacturer's representatives and these sketches would be the official records of the cavitation performance.

4.8 Air content measurement

It is the view of NEL that the air content of water being pumped during the evaluation tests is likely to remain normal (i.e. about 22 ccs/litre) for the following reasons.

(i) Relatively high NPSH values even for cavitation tests should preclude the possibility of substantial deaeration.

(ii) If air does come out of solution, it will be brought rapidly under high pressure, encouraging reabsorption firstly in the model pump and up to the No 1 breakdown valve, secondly at a reduced but still high pressure between Nos 1 and 2 breakdown valves, and finally in the reabsorber. There is no evidence to show that there is further deaeration at No 3 breakdown valve.

(iii) In fact excess air is likely to be entrained directly downstream of No 3 valve, where the jet is diverted into the sump. This free air, however, will mostly rise to the surface and escape in the relatively long and slow passage down the main bay sump to the Nos 1 and 2 booster pump intakes.

However, air content measurements will be taken using the NEL modified Van Slyke apparatus[ref. 8] at the start and end of each test run, Fig. 40.

4.9 Specific gravity measurements

The specific gravity of the water being used in the Evaluation Tests will be checked daily while they are in progress. The apparatus for carrying out this measurement is situated over the far end of the sump in the main building. A photograph is shown in Fig 38. The nearly bouyant sphere is weighed first in distilled water and then in the water used for NEL tests to obtain the specific gravity of the test water. The use of this apparatus and the corrections to be applied are described in detail in Ref.[8] which shows that it produces results with a standard deviation of only ±7 parts in a million by comparison with tests carried out with the National Physical Laboratory apparatus at Teddington near London. The latter is believed to be the most sensitive instrument for the measurement of liquid density in the country.

The specific gravity (as defined above) of the water used at NEL does in fact vary due to the slightly unstable chemical nature of the corrosion inhibitor used, but the variations are small as shown in Table 4. The inhibitor, sodium nitrite, will be added at the incoming water treatment plant at the rate of 0.1 per cent by weight.

4.10 Acceleration due to gravity

The value of g , in various parts of the Reynolds building, at NEL, was measured by University of Glasgow staff in 1956 and the mean value was found to be 9.80665 m/s^2 (32.2031 ft/sec^2). It is not proposed to repeat the experiment, as the value is unlikely to have changed significantly.

4.11 Temperature

Calibration of all thermometers to be used in the Evaluation Tests will be carried out in April 1967.

The thermometers which directly affect data evaluation are as follows.

(i) Pump inlet temperature - resistance thermometer with chart recorder

(ii) Piston gauge manomecer temperature - mercury in glass

(iii) Inlet manometer temperature - mercury in glass

(iv) Test house air temperature - mercury in glass

(v) Fortin barometer temperature - mercury in glass

4.11.1 Inlet temperature measurement

A 'Degussa' resistance thermometer is connected in a forced current balanced bridge circuit. The amplified bridge output voltage positions the slidewire tap of a Sunvic strip chart recorder Type RSP1 so that just sufficient current is fed back via a range resistor to maintain bridge balance.

Using the thermometer's nominal characteristics, the other elements of the bridge and the range resistor can be calculated. Final calibration to within $\pm 0.1^{\circ}C$ over the band 25 to $30^{\circ}C$ consists of comparison with a mercury-in-glass thermometer in a temperature-controlled water bath. A variable resistor across the reference arm sets the scale zero, while the range resistor is trimmed for full scale reading. Having set the desired span, intermediate points are marked directly on the scale which is then sub-divided.

A re-calibration with at least ten points will be carried out at the time of the observers meeting in April 1967.

5. Safety Measures

All participants in the Evaluation Tests are expected to bear some responsibility for safety. The most obvious danger area is in the pump test house itself, where room is restricted, there is a 11 000 V supply, maximum water pressures, and highly stressed machinery. Inside the door of the main electrical control room in the test house is a switch for stopping the 4000 hp motor. Anyone who considers, rightly or wrongly, that a dangerous situation is imminent, is empowered to throw this switch without reference to anyone else. No harm will be done, and if the alarm proves to be false, the result will be a loss of 30 minutes of testing time compared with anything up to catastrophic delays if the emergency became real and was not stopped.

The National Engineering Laboratory take the responsibility for the safety of their own equipment, while the manufacturers representatives are obviously best qualified to judge whether their model pump is running safely. In addition to the intercommunication system, emergency stop buttons are fitted both in the control panel and in the vicinity of the pump. Pressing either of these buttons sounds a (horn) in the switch room. If the (horn) sounds, the person nearest to the switch should throw it. Normally this person would be the MPBW electrician, who is always in this room, or only a few feet away checking bearing temperatures throughout the period of running of the main motor.

A fire extinguisher is situated immediately inside the door of the pump test house, next to the telephone. At night a fire, ambulance or police call may be made by dialling 999 either on this instrument or on the telephone in the messenger's booth in the foyer of the Reynolds building. Fire fighting apparatus is distributed through the main building and observers will be asked to take note of it and of the position of the first aid room situated on the first floor of the main building. Participants in the Evaluation Tests who have had first aid or medical training will be asked to note this when signing in nightly. NEL will provide at least one such qualified member of their staff.

No one should go alone at night to remote parts of the main building. Station 5 should normally be manned by at least two people (one of whom may be an observer).

The safety arrangements in the switchroom and for the motor comply with British statutory requirements. The motor is shielded against spray from burst pipes. It is proposed to build a safety screen between the test team and the test stand area which is already bounded by a low brick wall to prevent flooding.

It should be noted that the NEL circuit is protected from over-pressure not only by the vigilance of the test controller at Station 1, but by the following automatic controls.

> Valve control switches - if pressure builds up downstream of Valve No 1, manual control is overridden and it starts to close automatically. During this period it is impossible to close Valves 2 and 3. If pressure nevertheless continues to build up to danger level, the main motor is automatically tripped.
>
> Similarly, if pressure builds up downstream of Valve No 2, it starts to close. During this period it is impossible to open further Valve No 2, nor to close Valve No 3. If pressure continues to build up to danger level the main motor trips.

A pressure build up downstream of Valve No 3 is more serious. A similar arrangement is made for it to open automatically in the case of pressure build up, and Valves 1 and 2 cannot open further, but there is a tendency for Valve No 3 to become sluggish or to fail to move under a heavy back pressure. There is thus more likelihood at this position for the danger level main motor trip to come into operation than at the other two positions.

It is, however, the duty of the controller to prevent such situations arising, and, as already mentioned, tripping of the main motor is completely safe and would only cause a delay.

The model pump under test could be damaged if it ran dry or under heavily cavitating conditions due to the failure of a booster pump or pumps. There is an interlock which makes it impossible to start the main motor unless No 1 booster pump is running, and a failure of this pump would automatically trip the main motor. A further optional interlock may be switched into the circuit by the Station 1 operator if needed, which brings in No 3 booster pump. Both this pump and the main motor would then trip out if No 1 failed, and if No 3 pump itself failed, this too would trip the main motor.

The warning lights and switches associated with the pressure switch and motor trip circuits are included in the control panel at Station No 1.
The automatic safety arrangements will be checked out one week before each bidders model test.

6. MODEL PUMP TESTS

From the technical point of view all tests have the same basic structure, much of which has been described in some detail in Section 3 and 4. Table 5 typifies the schedule for the basic procedure, applicable to preliminary and official tests, and for normal and cavitation testing. The times of day given are not rigid, but are realistic and typical for completely trouble-free testing. It is, of course, of overriding importance to postpone the recording of results until all measuring stations are completely confident that the data they are about to obtain will be valid. No rigid timetable can be adhered to, therefore, during the testing period.

It should also be noted that the programme provides for only one break, of one hour, in a night shift from 20.00 to 05.00 the next morning. Between the times given in Table 4, of 2100 to 2400 and 0100 to 0400 hours, maximum concentration is demanded of the test team. The situation could conceivably arise where the testing period might be prolonged to more than the desirable three-hour maximum. In exceptional cases, an unbroken testing period of up to an absolute maximum of five hours may be necessary. It will then be the sole responsibility of NEL to judge whether tests can be resumed that night, even after one hour's rest break.

The period up to 31st August has been allowed by NEL for completion of the test programme on the three bidders model pumps. A minimum of six weeks must be allowed for installation and dismantling, and six weeks for testing on the basis of no contingencies. The period allowable for contingencies is, therefore, strictly limited.

It is unreasonable to allow any one bidder more breakdown time for adjustments, modifications, or replacement of faulty parts than either of the others. Further, NEL, whose equipment must function correctly throughout the tests, must also be allowed contingency time. If the situation arises when it appears inevitable that the schedule is about to fall behind, the DMJM engineer, after consultation with the manufacturer and NEL, may at his discretion instruct the manufacturer to withdraw his pump, and to re-apply for testing at a later date if and when the cause of malfunctioning has been rectified at the manufacturer's works. Permission for such a retest will be granted only if the time can be made available without interfering with the testing of other bidders models within the total time available for the test programme.

Any adjustment, modification or replacement of parts required during the Official Tests (Sections 6.2 and 6.3) may be carried out only by mutual consent of all parties and such changes and resultant actions will be recorded for inclusion in the subsequent Test Report.

(i) If, in the opinion of both the NEL Chief-of-Tests and the DMJM/MC Engineer, the change made could not have affected the performance of the pump, the tests will be continued.

(ii) If the reason for making the change gives doubt as to the validity of the data on hand, a sufficient number of re-runs will be made to determine the acceptability of the previously gathered data. If after making a change there is not correspondence of new data with the old, the data to be accepted will be determined after mutual analysis of the circumstance with the final decision resting with DMJM/MC.

(iii) If the tests are declared ended, evaluation may be made on the data taken up to the point of change if, in the opinion of DMJM/MC, these data are sufficient. If necessary, data taken at a lower test speed may be declared Official by DMJM/MC for the purposes of bid evaluation.

6.1 Test Programme

The test programme is shown in Table 6 and reading sequences in Table 7. All points in the sequences must be valid. Thus if the Chief of Tests decides that any of the measurements associated with any one of the flow settings will be discounted for the purpose of evaluation, the test point will be repeated.

The prototype and model performance criteria will have been supplied prior to the tests to NEL by the manufacturer (Table 1 of Specification No 637-1-2[1]). The rated flow Q_o will be calculated from

$$Q_o \; ft^3/s = \frac{315 \left(\frac{D_1}{D}\right)^3 \times \text{Test speed (rev/min)}}{600}$$

where D^1/D is the manufacturer's preliminary scale factor.

The NPSH for Test Series 2 onwards will be maintained constant during the tests within a tolerance of $^{+2}_{-0}$ feet of water. The required NPSH is to be based on that which gives the required suction specific speed at the rated flow Q_o

$$NPSH = \left\{ \frac{\text{Test speed rev/min} \times (Q_o \text{ US gal/min})^{\frac{1}{2}}}{\text{Suction specific speed}} \right\}^{\frac{4}{3}}$$

For the performance tests, the suction specific speed is to be 7000. For neither performance nor cavitation tests will it be practicable to evaluate the required NPSH for each individual flow setting, because of variations of the speed of No 3 booster and model pump with mains frequency, minor changes of barometric pressure and variations of vapour pressure with temperature over the permissible range (25° to 30°C). Instead after measuring the barometric pressure immediately before the tests begin, the NPSH and hence the inlet head will be calculated for the nominal test speed and the associated flowrate, neglecting subsequent changes during the tests of speed, barometric pressure, and vapour pressure. The last of these will be taken as that associated with 30°C - i.e. 1.42 feet of water. The inlet head relative to atmosphere will then be set as nearly as possible ($^{+1}_{-0}$ feet) to the value based on the above calculation. This procedure will result in the specified suction specific speed being met within a tolerance of $^{+1}_{-0}$ per cent.

All tests on the bidders model except those in Test Series No 1 will be invalid unless attended by the nominated representatives of NEL, DMJM, and the manufacturer of the model under test.

Before these tests, these representatives must have witnessed, checked and initialled calibration data sheets. After each test point has been taken, representatives must initial, after checking as far as possible, all test data sheets for that point. Initialling of data sheets does not necessarily mean that they are approved, or that every reading taken has been witnessed. This would clearly be impossible. It will be done to ensure that readings taken at the time of test are not altered in any way before being evaluated. The No 1 Station control sheet will be collected at the end of the night's run and kept secure with the data books in the NEL safe, as shown in Figs 41-43.

All test data will be entered in separate data books. The controller's at Station 1 is not replicated but those at the other stations are. It is planned that at the end of the first test period, before the rest break, the books in use during that period will be taken to the data processing centre for card punching, and the duplicates used until either the end of the test period, or until the card punching of the first set has been completed, in which latter case the books would again be exchanged. Any alterations made as a result of the discovery of mistakes when checking the data sheets prior to initialling must be individually initialled by all parties concerned.

NEL will be the sole holders of the raw test data, although observers will be asked to check and confirm that this data corresponds to that processed by the computer. During the test period, therefore, the only data issued by NEL will be the two copies of the computer output, one held by NEL on behalf of DMJM/MC, and the other by the manufacturer. This aspect is dealt with more fully under the sections on data collecting, checking and processing, and on security.

6.2 Test Series No 1: Commissioning Tests

These tests will be carried out after the pump has been installed and all concerned are satisfied that the pump, together with the testing complex, appear to be in satisfactory working order. They will be carried out solely to confirm this belief, and to put right any functional disorder which may have been overlooked. Tests will be carried out at 1500 rev/min at a flow approximately equivalent to the scaled-down Tehachapi duty. Tests at other conditions in the range covered by the official tests may also be conducted.

Correct functioning of all measuring equipment, of the control and communications system, as well as that of the pump, will be confirmed. Data will be entered on data sheets of the form used for the official tests, and processed through the computer the following day. The data from these commissioning tests will have no validity with respect to the final evaluation of the model pump. This means that after this data has been examined it will be held by NEL and not distributed. Fig. 41 shows the data flow chart illustrating the movement of data and computer print-out sheets.

6.3 Test Series No 2: Performance Tests at 1500 rev/min

These tests are to be similar to the first group of tests specified in reference 1 and are to be carried out over a wide flow range from 0-110 per cent of the rated flow in the sequence shown in Table 7, to establish the overall performance characteristics in conditions where the model will be under less severe mechanical stress when working away from the design point than at the subsequent higher test speeds.

The procedures, including data handling (Fig. 42(a)) for this test will be handled exactly as for the official performance test at 2750 rev/min except that the acceptance form will be that given in Appendix 3(a).

It is anticipated that these tests at a nominal speed of 1500 rev/min will be completed in one night. During the following day the gear wheels will be changed to give a new speed, selected by the manufacturer, so that the model pump can be run at this new speed again for one night only. It was agreed at the Observers Briefing meeting that the second speed should be 2250 rev/min.

6.4 Test Series No 3(a) and (b): Performance Tests at 2250 rev/min

As shown in Tables 6 and 7, these tests are concentrated in the region of the rated flow, to provide potential evaluation data in the event of mechanical failure at the official test speed of 2750 rev/min. Data will be handled as shown in Fig. 42(b) and the acceptance form will be that given in Appendix 3(b).

6.5 Test Series No 3(c) and (d): Cavitation tests at 2250 rev/min

These tests represent effectively only two test points. At each of the two settings, direct visual and photographic records will be taken. Visual observations will be noted on the cavitation observation sheet, to be prepared when information from the manufacturers is available, see Sections 4.6 and 6.7.2. These sheets will be subject to the same security as the other test data, and any observations or sketches made on them must be signed by NEL, DMJM, and the manufacturer. While visual observations are being taken, performance data will be obtained in the usual way. A series of repeat performance readings will be taken at each of the two test points if the time of taking visual records is greater than that required to obtain the performance data.

An independent speed counter at the cavitation observation site will be provided, and readings from this, together with the time of day, must be correlated with the cavitation records. This is necessary because it will not be practicable to synchronise all the visual observations required to take place within the 30-second flow diversion interval over which the associated performance data will be recorded.

The manufacturer's representative has 24 hours to consider the results obtained at this speed before signing the acceptance form (see Appendix 3(b)). The test programme will be suspended for one night after the Chief of Tests is satisfied that adequate data has been obtained to enable the manufacturer's representative to make his own study. Approval must be given by 09.00 hours on the following morning so that the gear wheels can be changed to 2750 rev/min. If it is not mechanically possible with a model pump to carry out tests at the full speed the manufacturer's representative would be allowed the full five days for study allowed for the final acceptance form. (See Section 7.6).

6.6 Test Series No 4(a): Official Performance Tests at 2750 rev/min

The specification 637-1-2 called for the performance of the pump to be evaluated from results obtained from three separate sequences.

(1) 12 flow settings equally spaced in the range 10 to 110 per cent of Q^1_o

(2) A series of flow settings at 2 per cent intervals in the range 90 to 110 per cent of Q^1_o

(3) 20 flow settings equally spaced in the range equivalent to 295 to 335 ft^3/s prototype flow, as determined from the manufacturer's preliminary scale factor D^1/D.

All points in the above sequences should be fully valid. Thus if the Chief-of-Tests decides that any of the measurements assooiated with that flow setting will be discounted for the purposes of evaluation, the test point will be repeated.

As noted above, at the Observers Briefing meeting 18th-21st April, 1967, it became apparent that difficulties might be experienced in obtaining the full data required in the above specification. It was decided to extend the programme by carrying out the additional tests described in Sections 6.2, 6.3, 6.4 and 6.5 and to arrange the sequence of testing at the official speed of 2750 rev/min in such a manner that the less important data at flow settings where vibration and thrust troubles might be experienced were obtained last. These tests are described in this and the following sections. The form of acceptance for these tests is given in Appendix 3(c). Reference should also be made to Section 7 and particularly to Section 7.6.

Test Series 4(a): efficiency evaluation tests will be made solely within the ±6 per cent range about the design flowrate listed in Table 7. The manufacturer shall inform the NEL Chief-of-Tests beforehand if he wishes to place any restrictions on the flowrate to be set at the time of the start up of the main motor, and of the estimated power absorbed by the pump associated with the minimum permissible flow once synchronous speed is reached (2750 rev/min). NEL will attempt to comply with such a request, but if the start cannot be made because of the high loading the start will be made at a lower flow setting, the valve being opened up immediately synchronous speed is reached.

It will be noted that point No 1 in the sequence given in Table 7 will be repeated five times, and also that the test point at the end of this sequence is a further repeat of the same 100 per cent flow setting. These repeats are to check consistency at the actual time of test. Repetition of readings for the same flow setting enables a rapid appraisal to be made of the functioning of the various instruments being used, as it is much quicker to analyse the deviation of a series of measurements from a single point than it is to obtain the deviation from a curve. If the motor is shut down at any time during the sequence of the official performance tests, then the last valid test point before shut down will be repeated with as nearly as possible the same control settings when the motor is restarted. With these precautions it will be possible to analyse the data to obtain checks on the reliability of the results and to ensure that no drift in the performance of the model pump takes place. Further consideration of this is given in Section 7.

6.7 Test Series No 4(b): Official Cavitation Tests at 2750 rev/min

Tests are required at suction specific speeds of 6000, 7000 and 10 000 (US gal/min basis), at the flowrate corresponding to the prototype head of 1970 feet of water developed at 2750 rev/min.

This flowrate will be determined from the results of the performance tests. The NPSH required to set up the specific speed will be calculated using the same basic assumptions of constant speed and temperature as given in Section 6.1. Therefore, to ensure that the three required suction specific speed conditions are covered, nine test points will be taken, at nominal specific speeds as defined in Appendix 1.

a	b	c
5900	6900	9900
6000	7000	10 000
6100	7100	10 100

For all the three sets a, b, c, of suction specific speeds the flow will be kept constant within ± 0.3 ft^3/s, and only the value of H_i altered to increase suction specific speed by the nominal increments of 100, 100, 800, 100, 100, 2800, 100, 100.

The values listed above are, of course, only nominal and the correct values will be calculated from the data sheets and used in the evaluation of results.

6.7.1 Control of cavitation tests

Tests will be carried out at increasing values of suction specific speed, i.e. decreasing values of H_i.

Initially, the required flow will be set with the maximum boost pressure available from the three booster pumps (Nos 1 and 2 at full speed, No 5 valve closed, No 4 valve fully open, No 3 booster on) (Figs Nos 2(b) and 10).

H_i will be reduced as necessary in the following phases

Phase 1. Opening valve 5 (bypass)

Phase 2. Valve 5 fully open. Closing valve 4 (No 3 pump discharge valve)

Phase 3. Valve 4 closed. No 3 booster off. Decrease speed of Nos 1 and 2 pumps.

Phase 4. Nos 1 and 2 pumps minimum speed. Valve 5 closing.

In practice, it is expected that Phase 4 will be unnecessary to achieve the maximum required suction specific speed.

As H_i is decreased as described above, the flow will decrease slightly. When the required value of H_i has nearly been reached, the flow will be corrected by trimming valves 1, 2 and 3 in such a manner that the flow increases, and there will be a further small drop in H_i. Since required suction specific speed is being met only approximately, a slight 'overshoot' in controls need not be corrected, and thus there will be no need at any stage to increase H_i.

The 'FLOW SET' signal will then be given, and readings taken in exactly the same manner as for normal performance tests. Any notes or photographs concerning visual observations of cavitation should be taken only during the period while the 'FLOW SET' signal is displayed. The same numbers will be used to identify the visual observations as will be used to identify the concurrent test data. As far as possible, such observations will be made during the 'DIVERT' phase when pump speed is being recorded. Where this is not possible, the speed shall be independently recorded by the visual observers, who will be provided with a counter conveniently placed for this purpose.

At intervals of not less than 20 minutes (i.e. the time to take two sets of performance readings), the air content of the water being pumped will be measured with the NEL modified Van Slyke apparatus(9), until such time when, if readings are remaining unchanged, it may be agreed to increase the time interval between the air content measurements.

It was agreed at the Observers Briefing meeting that the sequence of changing pressure described above, by changing valve settings etc., would be the same for the tests on all three model pumps.

6.7.2 Observation of cavitation patterns

At the Observers Briefing meeting, the question of the best method of observing and recording the actual cavitation pattern on the blades was discussed and it was agreed that visual study would be the most reliable (see also Section 4.6). The manufacturers agreed to provide sketches showing the view seen through the windows and NEL would reproduce sufficient number of copies of these sketches. For each test condition the DMJM/MC representative will draw the cavitation pattern and he, as well as the NEL and manufacturer's representatives will initial the sketch as being approved.

It was also agreed that the blades would be marked to facilitate this examination. The method to be adopted was that the manufacturers would paint a single line in the direction of the flow over the blade to mark blade No 1, two lines on blade No 3, three lines on blade No 5 etc. They would be examined by the DMJM/MC and NEL representatives prior to the start of the tests so that their size and position relationship could be marked on the sketches to provide a scale for comparisons.

6.8 Test Series 4(c): General Performance Tests at 2750 rev/min

With the successful completion of the above tests, a final series of tests will be made to obtain as much of the complete performance characteristic as is possible, the manufacturer's representative having the right to stop the tests if he considers that the pump would fail or be damaged because of excessive vibration etc. The Chief of Tests who is responsible for the safety of all the equipment on the test rig can deoide not to pursue the tests at an earlier stage, if he oonsiders these are endangered.

These general performance tests will be carried out at the intervals prescribed in the offioial contraot specification starting with the 100 per cent flowrate setting, followed by the 110, 108, 92, 90 per cent settings and then by systematically reducing the flow to obtain the 80, 70 eto. per cent settings as shown in Table 7.

7. PROCESSING OF EXPERIMENTAL DATA

7.1 General

As pointed out in the Introduction the purpose of the model pump tests to be carried out at NEL is to obtain head, flow, efficiency and cavitation data which can be used in the prototype bid evaluation. In this Section the measurements and constants required as raw data from which the performance of the pump can be determined are listed, together with the equations needed in the computation and the method of presentation of the results both for efficiency and for cavitation performance. Table 8 lists the documents required to process the raw data.

The actual evaluation will be carried out by the Laboratory's Univac 1108 computer and an open example of the computer sheets showing raw data input and calculated output is given in Appendix 6. In addition to the direct evaluation of the raw data, NEL has a computer programme for the analysis of the results by which curves can be fitted to the H-Q, P-Q and η-Q sets of results. Values of H, and η derived from the curves for selected values of Q and the maximum efficiency value obtained from the curve can be calculated. This analysis is based on the Method of Least Squares as required in ref. 1. The computer programme was designed to indicate if any test points fall outside prescribed limits (see Section 7.5).

In the following sub-sections the data and equations are given together with a statement of the methods of analysis.

7.2 Equations to obtain head, flow and efficiency

The head, flow and efficiency are required to be corrected to a model pump speed of 2750 rev/min. In the actual tests the speed may vary over a relatively narrow band around 2759 rev/min so that the normal affinity laws may be used, without introducing any error, to correct the actual values to those associated with a speed of 2750 rev/min. These affinity laws are based on the adequate assumption that the efficiency remains unaltered for small speed changes. Thus,

$$Q_3 = \left(\frac{2750}{N_1}\right) Q_1; \quad H_3 = \left(\frac{2750}{N_1}\right)^2 H_1; \quad P_3 = \left(\frac{2750}{N_1}\right)^3 P_1$$

The suffices, 1, for the actual values and, 3, for the derived values at 2750 rev/min have been used in the computer programme output since an intermediate calculation stage, 2, is used in that computation.

<u>Pump efficiency</u> $\eta = \dfrac{\text{water horsepower}}{\text{horsepower to pump shaft}}$

$$= \frac{\text{whp}}{\text{bhp}} \times 100 \text{ per cent}$$

<u>Water horsepower</u>

$$\text{whp} = \frac{\gamma_{F} Q\, H}{550} \text{ horsepower}$$

Brake horsepower to pump shaft

$$\text{bhp} = \frac{2\pi NT}{33\ 000} = \frac{N\ T}{5252.1} \quad \text{horsepower}$$

Flowrate
$$Q = \frac{s.\ W}{t} \quad \text{cusecs}$$

Total pump head
$$H = H_d + H_v - H_i \quad \text{ft } H_2O$$

Pump torque
$$T = C_L \left\{ 0.5 \left(\frac{mV}{V} + \frac{mV_R}{V} \left(\frac{N}{N_R} \right)^2 \right) - \frac{mVo}{Vo} \right\} + 188.0 \quad \text{lb ft}$$

7.3 Equations to obtain cavitation results

Net Positive Suction Head

$$NPSH = H_i + h_{iv} + H_a - H_{vp}$$

Speed corrected NPSH
$$(NPSH)_2 = NPSH \left(\frac{2750}{N} \right)^2 \quad \text{ft } H_2O$$
No corrections to NPSH for flow changes are made.

Pump total head corrected for speed and flow

$$H_{2c} = H_2 + \frac{\delta H}{\delta Q} \Delta Q \quad \text{ft } H_2O$$

Cavitation coefficient
$$\sigma = \frac{(NPSH)_2}{\frac{1}{4} \cdot H_{2c}}$$

Suction Specific Speed
$$S = \frac{N\ (Q\ \text{USgal/min})^{\frac{1}{2}}}{(NPSH)_2^{\frac{3}{4}}}$$

Q US gal/min is taken to equal 449 Q cusecs for purposes of calculating Ns and S in above equation.

In the above equations, small corrections are made to obtain the cavitation performance since it is not possible to set the speed and flow to exact values for each test point. In the equation for pump total head
$$H_2 = H \left(\frac{2750}{N} \right)^2$$

$\frac{\delta H}{\delta Q}$ is the slope of the head/flow performance curve at the nominal flowrate for the cavitation test series.

ΔQ is the difference between the actual flowrate for the particular test point and the nominal flowrate for the cavitation test series.

The slope of the head/flow performance curve will be obtained directly from the official performance tests at the nominal 2750 speed.

7.4 Constants and calibration data

Appendix 1 lists the constants to be used.

Flowrate

The weight of water diverted and the time of diversion involve the weighbridge and timer and both will be checked to ensure that they are correct at the time of the Observers' Briefing Meeting in April 1967. Thermometers used to measure water and air temperatures will be checked against NPL calibrated thermometers.

The specific weight of distilled water will be taken for the appropriate temperature from Standard Physical Tables.

The specific gravity of the actual water passing through the pump will be measured daily and this ratio, usually between 1.0015 and 1.0025, will be entered as a constant on the raw data computer sheets.

Pump Total Head

Each manometer used for the suction head measurement will be separately calibrated and the calibration constant used as a multiplier to convert from inches mercury to feet water. The temperature correction is a direct one to convert the height measured to the head of water at the pump water temperature. The mercury/water density ratio takes into account the specific weight of the pump water. The calibration details will be entered on a sheet, a specimen of which is shown in Fig. 26.

The piston gauge manometer will be calibrated nightly against a standard deadweight tester. The calibration constants will be inserted in the computer data sheet. The weights used on thepiston gauge manometer are all accurate to a higher order of accuracy than required. A specimen calibration sheet is shown in Fig. 33.

The value of 'g' has been established locally.

Pump torque

The torque tube will be calibrated before and after the official tests on each pump and the mean value used in the final computations. The pretest calibration constants will be used for all computations up to two days after the final test, on each pump. Fig. 21 shows a specimen calibration sheet.

Pump speed

The speed measuring equipment will be checked to ensure that it is correct to a higher order of accuracy than that required for the tests.

7.5 Curve Fitting

The results computed from the raw data will be in the form of flow, head, power and efficiency values corrected to the common model speed of 2750 rev/min. The computer programme also prints out H-Q and η-Q tables in terms of the percentages of the rated H and rated Q using the provisional D^1/D value. Curves will be plotted to show efficiency,

$$\eta, \text{ P and } \frac{H}{H \text{ rated}} \times 100 \text{ as functions of } \frac{Q}{Q \text{ rated}} \times 100.$$

The computer programme used to fit these curves to these values adopts the method of least squares and uses orthogonal polynomials. To ensure high accuracy the values of the flowrate are first normalized to lie between -1 and +1 by obtaining values of

$$X = \frac{2Q - (A + B)}{B - A}$$

where B is equal to 0.001 more than the highest value of the flowrates, Q, being fitted and A is equal to 0.001 less than the lowest value. Double length arithmetic (approximately 16 decimal digits accuracy) is used throughout the fitting.

After the curve has been fitted to the 94-106 per cent set of test points, for example the H-Q set, the scatter or standard deviation of the points about the curve is computed and printed out. Any test points lying more than 2.60 times the standard deviation from the curve are marked with two asterisks in the tabulation and the complete set minus these points is re-fitted with a fresh curve. The same procedure is repeated until all the points lie within this bandwidth which is equivalent to statistical 99 per cent confidence limits. The same treatment is used for the P-Q and η-Q sets. In this way wild points caused by reading or punching errors are shown up. If after examination of the computer printout the cause of the error can be established and corrected the data will be re-run. If the cause cannot be clearly located then the point is invalidated. It is expected that the bandwidth selected will eliminate any points more than 0.5 per cent from the curve; if it does not then these points* will also be invalidated and retested. If more than one-third of the test points obtained during a selected period, for example a night's run, are rejected during the computer analysis, the whole of the sequence of points will be re-run unless re-examination shows a clear cause for the rejections.

For the power and normalized head and flow test points over the bandwidth of approximately ±6 per cent from the design point, the best fitting curve of second order will be determined and the slope of the normalized head/flow curve obtained at the selected flowrate. This is used subsequently in the determination of the NPSH value for the cavitation tests.

For the efficiency test points in this same region a second order curve will be fitted to the η-Q set of results. The maximum value of this fitted curve within the equivalent flowrates to the prototype flowrates 305-325 cusecs using the formula given in the DMJM specification 637-1-2 will be calculated by the computer programme, together with the value of the flowrate at which this occurs. These values are the ones to be adopted for the sealing up for the official bid evaluation.

7.6 Contraotor approval

The procedure for the contraotors approval is given in the DMJM specifioation 637-1-2 and in Seotion 8 under Seourity. Each day the contraotor will have the opportunity to study the test data and results obtained from the computer. Any comments about individual test points will be examined by the Observers and the NEL Head of Fluid Mechanios Division or his appointed deputy. Test points accepted by the NEL representative as being in dispute will be re-run through the computer if it appears that a card punching or computer error has been made or deolared invalidated and re-tested if appropriate.

If after five days the manufacturer's representative does not accept the results obtained in the official tests, a meeting of the observers, NEL andmanufacturer's representatives will be held. They will determine why approval has not been made and if the observers and NEL representative rule that the reasons for disapproval are legitimate, then they (the DMJM/MC and NEL representatives) will decide what action and, if necessary, retesting shall be taken.

8. Security

8.1 General

It is necessary to maintain strict security over the details of the model pumps, test operations, and test results up till the bid opening for the Tehachapi prototype pumps. As a consequence, DMJM, MC and NEL have agreed upon certain rules that are presented in this section. It will be expected that all those connected with this programme will co-operate in the observation of these rules and thus ease the burden of their enforcement.

8.2 Personnel to be permitted access to the test operation

8.2.1 NEL staff

The members of the NEL staff with access to the test areas and data processing areas will be determined by the Head of Fluid Mechanics Division on behalf of the Director of the Laboratory and the number will be kept to a minimum.

8.2.2 Manufacturer's representative

During the testing of any one of the model pumps, the manufacturer of that pump will be required to have an authorized representative present during operation as well as having a mechanic available for tending the model. The manufacturer may send a delegation of representatives, but one will be selected prior to the testing as being in charge and having the authority for signing the Test Acceptance form and the others will be his assistants. The names of the man in charge and the assistants are to be given to DMJM before 15th April, 1967.

8.2.3 Observer team

On behalf of the Department of Water Resources, an observer team composed of DMJM/M-C personnel will monitor all tests. One member of the observer team will be present during all test operations, all data review periods and all meetings and conferences involving the manufacturer's personnel and the NEL staff.

The observer will sign all data etc., as having been a witness to its origination.

8.2.4 Visitors

All other persons permitted access to view the operation will be considered Visitors. Visitors will have no official duties. Visitors will not be allowed to be present in the test areas when data are being taken. Visitors will only be accepted if approved by DMJM/M-C, NEL and by the manufacturer's representative (except as governed in an emergency by the Ministry of Technology). Acceptable visitors may be either,

(a) Staff of the Ministry of Technology.

(b) Staff of the Department of Water Resources.

(c) Project staff of DMJM/M-C

(d) Staff of a model manufacturer during the period their model is under test.

or (e) Others having the express invitation of the Department of Water Resources.

In order for a visitor to be accepted, he should notify Dr. E. A. Spencer, National Engineering Laboratory, East Kilbride, Glasgow, of his intended visit at least 5 days in advance of arrival. Upon departure, visitors will sign a Visitors Record, a sample of which is reproduced in Appendix 2. This form will be handed to the visitor to read and sign on arrival and again handed to him to resign on departure.

8.3 General procedures

8.3.1 NEL correspondence

NEL copies of correspondence, test data, drawings, and other information dealing specifically with each bidder's model will be kept locked in separate cabinets from data concerning other models, and from any other NEL paperwork. The Head of Division, or in his absence his officially appointed deputy, shall be the sole possessor of keys to these cabinets. These keys will be kept in a safe in the Laboratory, and will not leave the site.

8.3.2 Access to office area

No personnel from outside NEL will be allowed access to the Reynolds building, which will be kept locked outside normal working hours, unless accompanied by a member of the NEL staff. A log book will be kept on the messenger's desk in the foyer of the building, in which all personnel must sign and record the time of entering and leaving during tests.

8.3.3 Office space

Manufacturers representatives and observers will be allocated temporary office accommodation during the tests. NEL staff will not enter these offices during tests without the consent of the occupants, whose responsibility it must be to clear the room of any confidential documents after each night of test. Similarly, there will be a reciprocal ruling regarding the remaining NEL offices. If there is a violation of these rules by any individual, he must be stopped and the incident reported in the log book.

8.3.4 Access to High Power Pump Test House

No one other than NEL personnel (which for this purpose also includes MPBW service staff) will be allowed in the high power pump test house during the entire programme period without an NEL escort. Persons wishing to enter the test room will first 'sign in' in the foyer of the Reynolds building and pick up an escort. Violation of this procedure will be noted in the log book.

The pump test house will be kept locked at all times when there are no members of the NEL staff inside.

8.4 Consideration of the model pump

The installation and alignment of the model pump will be performed by NEL staff and the manufacturer's representatives with mutual instruction and assistance. The manufacturer's representative will have the final authority in directing the handling of the model itself and making connection to it.

NEL staff will not open the model pump or perform any operation on the model without permission from and the direction of the manufacturer's representative (or mechanic). The safekeeping of drawings of the model pump will be the responsibility of the manufacturer.

No observer or visitor will be permitted in the pump test house when the model pump is open except with the permission of the manufacturer's representative.

At such times as the model is not operating or is operating but data are not being gathered, visitors may enter the pump test house with the permission of the NEL, the manufacturer's representative and the observers. Visitors will conduct themselves according to directions given by the NEL staff and manufacturer's representative and will leave the pump test house promptly when told to do so by the NEL Chief of Test. Visitors should not direct questions to members of the NEL test team. The latter have been told to refer any queries to the Head of Fluid Mechanics Division, or in his absence, to the NEL Chief of Test, the manufacturer's representative and observers.

8.4.1 Safe keeping of information on bidders model tests

At the Observers Briefing Meeting it was stated that the State of California's Department of Water Resources would not require any details of the test results prior to the bid opening. The rules set out in Section 8 limit access to the raw data and results of the tests to the minimum number of people regarded as essential to the proper conduct of tests and these rules were accepted. NEL agreed that the members of NEL staff involved in seeing the results would be Dr. E. A. Spencer, his deputy Dr. D. J. Myles, the Chief of Tests, Mr. R. A. Nixon, and selected staff, probably two, who check the computer print-out sheets and plot and initially analyse the results.

From the time that the data books are collected together to enable the computer cards to be punched, the information will be under the visual supervision of the appointed member of the NEL staff until it is lodged in the NEL safe and thereafter will only be handled in the NEL check rooms. Similarly the punched cards and the computer print-out sheets will be under visual supervision until they are lodged in the NEL safe. The computer memory will be erased each time after the programme has been used to analyse test data and the Tehachapi test material will be transported in a lockable case.

No information on the bidders model tests will thereafter be permitted to be taken out of the NEL check rooms (apart from the manufacturer's copy) all conferences and analysis being carried out in these rooms. Other security precautions have been taken elaborating the procedures referred to in this Section 8.

8.5 Test Operation

During actual testing, movement of personnel in the pump test house will be restricted. Only a single member of the manufacturer's representative team, and one member of the team of observers, will be allowed in the data gathering area. All others must stay on the opposite side of the motor unless express permission is given by the Chief of Tests for a specific purpose. No one other than NEL staff will approach the weightank station in the Reynolds building where the flowrate is measured unless escorted.

The manufacturer's representative and the observers will restrict conversation to the Chief of Test and each other. The manufacturer's representative may taken personal notes if he desires but he will be responsible for their safekeeping. Observers and visitors shall not take personal notes. Observers and the manufacturer's representative may write comments on the data sheets if they wish. When writing comments the person so doing shall place his initial by the comments along with the date and time of day and, if applicable, the test run number. Comments will only be added at the time the data books are brought to Station 1 for checking and signing off or during data check meetings with NEL staff and DMJM/MC observers present (see Figs 41 to 43 concerning data handling).

8.6 Data Handling

8.6.1 Types of data

The official documents produced during the testing shall be

For commissioning Test (1500 rev/min) - Test Series No 1

- I Laboratory Data
- II Punched Cards (for data input)
- III Computer Print-out

For performance Test (1500 rev/min) - Test Series No 2

- I Laboratory Data
- II Punched Cards (for data input)
- III Computer Print-out
- IV Test Acceptance Forms

For performance Test (2250 rev/min) - Test Series No 3

- I Laboratory Data
- II Punched Cards
- III Computer Print-out
- IV Test Result Acceptance Forms

For the official Tests (2750 rev/min) - Test Series No 4

I Laboratory Data

II Punched Cards

III Computer Print-out

IV Official Acceptance Forms

In Table 8 a list of documents is given which will be used in the analysis of the test data. These will be available for inspection by the manufacturer's representative and the observers on request to the Chief of Tests.

In each test type, continuing sets of data may be produced. In particular, the official tests will require more than one night of testing so that several data sets will ultimately exist.

8.6.2 Sequence of data handling and acceptance forms

The recording and collection of the Laboratory data has been explained in Section 7. The treatment of data from the point of collection will be as shown in Fig. 41, for commissioning Test 1500 rev/min, Fig. 42(a) for performance Test 1500 rev/min, Fig. 42(b) for performance Test 2250 rev/min and Fig. 43 for the official Test 2750 rev/min. As stated in Section 6 the acceptance form for the 1500 rev/min performance test will be signed off immediately after the raw data is reviewed at the conclusion of the testing. The acceptance form for the computed results of the 2250 rev/min performance test will be signed off after review on the day the computer print-out is available. It should be noted on the official test sheet that there will be a 5-day period allowed between the data check at NEL and the final signing of the official acceptance form. In the event that the official tests at 2750 rev/min are not sufficiently complete for all three models to permit the 20 point efficiency curve determination for the bid evaluation, then the 2250 rev/min performance results will be used instead and will be handled like the official results shown on Fig. 43 from the Contractor's 'Check Calculations and Results' position on the diagram onwards.

Samples of the acceptance forms are given in Appendix 3. The form shown in Appendix 3(a) covers 'Performance at 1500 rev/min - laboratory raw data'; Appendix 3(b) covers 'Performance at 2250 rev/min - laboratory raw data and calculations'; while Appendix 3(c) covers 'Performance at 2750 rev/min'.

Within 30 days after the bid opening, it is planned that NEL will submit to DMJM (for the Department of Water Resources) a final report with the computer runs, curves, etc., for all three models. This report will be treated confidentially.

8.6.3 Contractors approval of final test results and the official acceptance form

After the five-day period allowed for reviewing the performance data, the manufacturer's chief representative will meet with the NEL Chief of Test and the DMJM/MC observers. A 'Statement of Test Results and Acceptance' form will be completed in triplicate and the copies will be distributed to

Copy No 1 - DMJM/MC to be submitted to the State of California official at the bid opening for the Tehachapi pumps;

Copy No 2 - Manufacturer

Copy No 3 - NEL.

REFERENCES

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TABLE 1

LONG-TERM STABILITY OF NEL MAIN STANDARD WEIGHBRIDGE

FLOW MEASUREMENT SYSTEM BY DEADWEIGHT CALIBRATION

(Water weight checks have been carried out at intermediate times during this period)

Date of calibration	Cumulative error (lb) of mean error line at stated notch position on steelyard (1)	Steel-yard notch Position (3) (lb)	General scatter band of test points about mean error line (lb)	Remarks	Max. error at any point since previous calibration (lb)
March 1958	Nil	All (see remarks column)	±7	Calibration up to 20 000 lb	
May 1960 (2)	+20	50 000	±10		+37
July 1962 (2)	Nil	All	±10	Calibration up to 47 000 lb	+23
July 1963	-27	44 000	±10	Calibration up to 45 000 lb	-30
Dec. 1963 (2)	-20	60 000	±10	Calibration up to 67 000 lb	-22
May 1965 (2)	+13	60 000	±6	Calibration up to 68 000 lb	+20

Notes

1. In the cumulative error column + signifies steelyard indication heavy and vice versa.

2. In these tests, after the tank weight-loading procedure, the steelyard major poise was adjusted to compensate for mean error found and, in the unloading calibration, all notch positions were trimmed to within ±5 lb of truth.

3. The mean error line, if deviating from the true steelyard indication, gives either a positive or negative gradient passing through the values given in column 3 (above) and zero error at the empty tank balance, i.e. the mean error (heavy or light) tends to increase as the steelyard scale is traversed.

T A B L E 2

STATIONS AT WHICH TEST DATA ARE RECORDED

No	Function	Apparatus	Remarks
1.	Control and co-ordination	Control and communications panel	Data recorded on control sheet is for monitoring purposes only, and not for assessment of pump performance
2.	Torque and speed measurement	Digital readout of speed, digital and analogue readout of torque	Special notice to be taken of quality of U/V recordings before and after each test point
3.	Inlet head Measurement	Single limb mercury/water manometers in series	Notice to be taken of changes in level during diversion period, and of purging of lines during 'flow change' periods
4.	Discharge head measurement	Piston gauge manometer	As for 3 above
5.	Flow measurement	NEL 30-ton weighbridge	Look for steadiness and freedom of tank during weighing period, for absence of splash-out during diversion, absence of leak-in during 'NORMAL' condition, and for closure of air-bleed valve.
6.	Photography	High-speed camera illuminated by strobo-flash synchronised to pump shaft	
7.	Bearing temperature measurement	Thermocouples	For monitoring purposes only

TABLE 3

RANGE OF AVAILABLE TORQUE TUBES

No	Total Range lb ft	Range Limits for pump tests lb ft	Test
1	0 to 10 000	5400 to 10 000	Official performance and cavitation tests at 2750 rev/min
2	0 to 6000	3600 to 6000	Tests at 2250 rev/min
3	0 to 4000	1870 to 4000	Tests at 1500 to 2000 rev/min

The range limits given above apply only within the range of 90 to 110 per cent of the rated flow Q_0. Tubes will not be changed to accommodate the smaller torque values encountered in the range 0 to 90 per cent Q_0.

TABLE 4

VARIATION OF SPECIFIC GRAVITY OF WATER IN NEL TEST FACILITIES

Date	Temperature °C	Specific gravity	Per cent deviation from previous value	Per cent deviation from mean value
20.4.65	15.0	1.00202	+0.030	+0.011
21.4.65	16.0	1.00199	-0.003	+0.008
23.6.65	20.8	1.00205	+0.006	+0.014
30.7.65	21.3	1.00185	-0.020	-0.006
30.7.65	22.7	1.00187	+0.002	-0.004
13.8.65	21.8	1.00198	+0.011	+0.007
24.8.65	21.5	1.00204	+0.006	+0.013
8.10.65	18.0	1.001995	-0.004	+0.009
12.10.65	18.1	1.00204	+0.004	+0.013
22.10.65	17.6	1.00198	-0.006	+0.007
8.11.65	17.5	1.00207	+0.009	+0.016
11.2.66	21.4	1.00178	-0.029	-0.013
24.3.66	21.9	1.00205	+0.027	+0.014
7.7.66	20.8	1.00188	-0.017	-0.003
11.7.66	20.8	1.00190	+0.002	-0.001
20.7.66	25.4	1.00185	-0.005	-0.006
12.10.66	21.6	1.00166	-0.019	-0.025
19.10.66	19.5	1.00169	+0.003	-0.022
24.20.66	19.4	1.00160	-0.009	-0.031
	Mean value over period	1.00191		

TABLE 5

NORMAL TIMETABLE DURING TESTS

Time	Action required	Action taken by
0830 to 1700	Change gears	NEL workshop
	Calibrate piston gauge manometer	Experimental Officer (E.O.)
0930	Process data in computer	NEL operators
1430	Discuss processed results	Representatives of all parties concerned in evaluation
	Notify SSEB of proposed 2100 start	MOPBW
1600 to 1700	Check circuit, valve operation, communications, auxiliary machinery	E.O. and NEL mechanic
1700	Switch on electronic readout devices to warm up	E.O.
1930	Progress meeting at NEL (members to sign log book on arrival)	Representatives of all parties concerned in evaluation
2000	Start of night shift proper (log book to be signed on arrival)	Observers, test team, MOPBW etc.
	Switch on and test communications	Station 1
	Check with SSEB	MOPBW electrician
	Apply preset torque arm	NEL mechanic
	Take torque readings	Station 2
	Remove torque arm	NEL mechanic
	Check alignment	Manufacturer and NEL engineer to sign alignment record
2020	Couple model pump to torque tube	NEL mechanic
	Switch on 'FLOW CHANGE' and state of readiness displays. Press 'CANCEL' button to return all lights to 'NOT READY' and to check bell signal. Check 'EMERGENCY STOP' signals	Station 1

Time	Action required	Action taken by
2025	Start No 1 booster	Station 5
	Open valves in circuit	Stations 1 and 5, NEL Mechanic
	Bleed off air	Stations 3, 4, and 5 Manufacturer
	Purge instrument lines	Stations 3 and 4
2030	Read manometer zeros	Station 3, Observers
2040	Start extra booster pumps if required	NEL mechanic
2045	Clearance from SSEB	MOPBW electrician
	Start main motor and gearbox auxiliaries	MOPBW electrician
2050	Set breakdown valves for starting conditions	Station 1
	Note control panel readings on control sheet	Station 1
2055	Obtain clearance for start from all present	Station 1
2057	Lower brushes and prepare to take starting torque record	Station 2
2059	Final clearance	MOPBW, SSEB, Station 1
2100	Start	MOPBW electrician
	Three ring signal	Station 1
	Starting torque U/V recording	Station 2
	Observe for faults	All
2101	Raise brushes	Station 1
2102	Note control panel readings	Station 1
	Start cooling water circuit	NEL mechanic
2104	Set up for first test condition	Stations 1 and 5
2106	Check with manufacturer that pump is running satisfactorily	Station 1 Manufacturer's representative to sign pump log

Time	Aotion required	Action taken by
2110	Display 'FLOW SET'	Station 1
	Data oolleotor to Station 5	Station 1
	Record control panel readings	Station 1
	Lower brushes	Station 2
	Preliminary measuring operations	Stations 2, 3, 4, and 5
2115	4 green lights	Stations 2, 3, 4 and 5
	'CANCEL' - 1 ring (4 red lights)	Station 1
	Stand by ready to measure	All stations
2116	4 green lights	Stations 2, 3, 4 and 5
	Order station 5 to divert	Station 1
	DIVERT	Station 5
Simultaneously	'CANCEL' - 2 rings (4 red lights)	Station 1
	Start reading	Stations 2, 3 and 4
	NORMAL	Station 5
Simultaneously	'CANCEL - 1 ring	Station 1
	Stop reading	Stations 2, 3 and 4
	Leave meroury columns and P.G.M. weights for checking data sheets	Stations 3 and 4
	Data collector to Test House after checking weighing and time of diversion	
2117	Weigh tank (double check) then start emptying	Station 5
	Reverse bridge volt readings, U/V reoording, lift brushes	Station 2
	Collection and checking of data sheets	NEL
	Countersigning data sheets	Appointed observers
	Display flow ohange	Station 1
2120	Set up for next test condition	Stations 1 and 5

Time	Aotion required	Aotion taken by
2122	Cheok with manufacturer, display 'FLOW SET'	Station 1
	Data collector goes to Station 5	
	Repeat sequence 2110-2122 until	
2400	'CANCEL' - 3 rings, switch out FLOW SET/CHANGE panel	Station 1
	Data books to punch card centre	Data oollector
	Stop main motor	MOPBW electrician
	Stop cooling water ciroult	NEL mechanio
2405	Stop No 3 booster	NEL mechanio
	Slow down Nos 1 and 2 boosters to minimum	Station 1 or 5
	Break for 1 hour	All
0105	Start again as from 2040	
	Second set of data books issued to stations	Data colleotor
	Continue testing oycle until nights programme completed, say at	
0400	'CANCEL' - 3 rings, switoh out FLOW SET/CHANGE panel	Station 1
	Stop main motor	MOPBW electrician
	Inform SSEB 'End of Test'	MOPBW eleotrician
	Stop cooling circuit	NEL mechanio
0405	Stop No 3 booster	NEL mechanio
	Slow down Nos 1 and 2 boosters to minimum	Station 1 or 5
	Close No 2 booster disoharge valve	Station 5
	Stop No 2 booster	Station 1
	Close No 3 regulating valve	Station 1
	Close Nos 1 and 2 regulating valves	Station 1

Time	Action required	Aotion taken by
0405	Cheok manometer zeros	Station 3
	Break pump coupling	NEL mechanic
	Check alignment and sign reoord	Manufaoturer and NEL engineer
	Apply preset torque arm	NEL mechanio
	Take torque readings	Station 2
	Remove torque arm	NEL mechanio
	Final cheok through data sheets	NEL and observers
0445	Sign out	Observers
	Isolate oirouit, lock up	NEL staff and MOPBW
0500	Sign out	NEL test staff
0730	Card punching oomplete	NEL operator

TABLE 6

APPROVED TEST PROGRAMME

Test series No	Pump speed rev/min	Suction specific speed (based on rated flow)	Flow range percentage rated flow	Object
1	1500	As required	As required	Commissioning of NEL test equipment
2	1500	7000	0-110	Performance test
3(a)	2250	7000	94-106	Performance test
(b)	2250	7000	90-110	Performance test
(c)	2250	7000	100	Cavitation test
(d)	2250	6000	100	Cavitation test
4(a)	2750	7000	94-106	Performance test
(b)	2750	5900	100	Cavitation test
		6000	100	Cavitation test
		6100	100	Cavitation test
		6900	100	Cavitation test
		7000	100	Cavitation test
		7100	100	Cavitation test
		9900	100	Cavitation test
		10000	100	Cavitation test
		10100	100	Cavitation test
(c)	2750	7000	110-minimum as specified by manufacturer	Performance test

NOTES

(i) Suction Specific Speed. Where this is specified, a constant NPSH, based on the given suction specific speed at the rated flow, will be maintained, within a tolerance of $^{+2}_{-0}$ feet, over the given flow range.

(ii) Sequence of Test Points. The sequence to be used for test points (given in Table 6 in the earlier version) has been revised following the discussion at the Observers Briefing Meeting 18th-21st April, 1967. The new sequences are given in Table 7.

TABLE 7

TEST POINT SEQUENCES FOR OFFICIAL TESTS

Points	Sequence for test series No 2 10-110% rated flow by 10% steps	Sequence for test series Nos 3(a) and (b) 90-110% by 2% 93.64-106.35% with minimum of 20 points	Sequence for test series No 4(a) 93.65-106.35% with minimum of 20 points	Sequence for test series No 4(c) 10-110% by 10% steps 90-110% by 2% steps
1	100	100	100	100
2	110	103.2	103.2	110
3	90	94.3	94.3	108
4	80	96.8	96.8	92
5	70	103.8	103.8	90
6	60	100.6	100.6	80
7	50	90.0	98.7	70
8	40	98.7	102.5	60
9	30	110.0	101.3	50
10	20	102.5	94.9	40
11	10	101.3	97.5	30
12	100	94.9	105.7	20
13		97.5	104.4	10
14		105.7	96.2	100
15		104.4	93.7	
16		96.2	95.6	
17		108.0	106.3	
18		93.7	105.1	
19		95.6	98.1	
20		106.3	99.4	
21		105.1	101.9	
22		98.1	100	
23		99.4		
24		90.0		
25		101.9		
26		100		

NOTES

1. It should be noted that the % Q_0' values are not intended to be exact; circuit settings will, however, be expected to give results very close to these values.

2. Five repeat sets of readings of the first point in each sequence will be taken. Valve settings etc. will be left unaltered during these repeat reading periods.

3. After any pump shut-down, the settings immediately prior to the shut-down will be used to obtain a repeat of the last test point.

4. Additional test points will be taken during the tests if the Chief of Test is not satisfied with the readings obtained for any test point.

TABLE 8

DOCUMENTS REQUIRED FOR ANALYSIS OF TEST RESULTS

Document	Information given	Where available	Security level
NEL Procedure Report		Issued to all observers	As printed on cover of document
Appendix 1	Constants used in calculations for all Bidders Model pump tests		
Specific gravity log book	Daily value of specific gravity of sump water	Held by NEL flow measurement section	Unclassified
Torque tube log book	Derivation of CL value	Held by NEL Chief of Test or Head of Division	Unclassified
Piston gauge manometer log book	Values of 'K' and 'C'	Held by NEL Chief of Test or Head of Division	Unclassified
Torque tube calibration sheets	Values associated with preset torque	Held by NEL Chief of Test or Head of Division	Unclassified
Single limb manometer calibration sheets	Zero reading values	Held by Chief of Test or Head of Division	Unclassified
Steam tables	Vapour pressure of water	From Head of Division	Unclassified
Raw data sheets	Readings taken during tests	Held by Head of Division	Maximum
Computer print-out sheets and punched cards	Test results	Held of Head of Division	Maximum

T A B L E 9

SCREENS FITTED IN PUMP CIRCUIT (SEE FIGS 1a, 2b AND 44)

Screen No	Mesh Size	Details
S1	Single row of fine $\frac{1}{8}$ inch mesh	Located in sump upstream of Nos 1 and 2 Booster Pumps to prevent foreign material entering booster pumps
S2	Heavy $\frac{1}{2}$ inch mesh	Located just upstream of No 3 booster pump
S3	Heavy $\frac{1}{2}$ inch mesh	Located at discharge flange on No 3 booster pump
S4	Fine $\frac{1}{8}$ inch mesh	Located at upstream flange of 180° bend upstream of model pump
S5	Double row of mesh upstream row $\frac{1}{16}$ inch mesh followed by $\frac{1}{32}$ inch mesh	Located in sump downstream of flow from diverter and weightank emptying pump

TABLE 10

VALUES OF S USED IN FLOW MEASUREMENT DETERMINATIONS

The specific weight of the water flowing through the pump is determined from the mass density of distilled water and the specific gravity of the water in the sump, allowing for buoyancy and the actual temperature of the water. This is determined in the computer programme from an equation for the density of water (from N. E. Dorsey Properties of ordinary water substance New York: Reinhold Pub. Corp., 1940).

$$\text{Density} = 1 - \frac{(\theta_p - 3.9863)^2(\theta_p + 288.9414)}{508\ 929.2(\theta_p + 68.129\ 63)}(999.973)\ \text{kgm/m}^3$$

and, for the specific volume factor (reference 9), by linear interpolation over the range of temperatures from 13-35.5°C in the following tables where,

$$S = S_{1.0020} + x \times 10^{-6}$$

Temp. °C	$S_{1.0020}$ ft^3/lb	Temp. °C	$S_{1.0020}$ ft^3/lb	Temp. °C	$S_{1.0020}$ ft^3/lb
13.0	0.016 013	21.0	0.016 035	29.0	0.016 068
13.5	14	21.5	37	29.5	71
14.0	15	22.0	39	30.0	73
14.5	16	22.5	40	30.5	75
15.0	18	23.0	42	31.0	78
15.5	19	23.5	44	31.5	81
16.0	20	24.0	46	32.0	83
16.5	21	24.5	48	32.5	86
17.0	23	25.0	50	33.0	88
17.5	24	25.5	52	33.5	91
18.0	25	26.0	55	34.0	94
18.5	27	26.5	57	34.5	96
19.0	29	27.0	59	35.0	0.016 099
19.5	30	27.5	61	35.5	0.016 102
20.0	32	28.0	63		
20.5	0.016 033	28.5	0.016 066		

sp.gr.	x	sp.gr.	x	sp.gr.	x	sp.gr.	x
1.0010	+16	1.0015	+8	1.0021	-2	1.0026	-10
1.0011	+14	1.0016	+6	1.0022	-3	1.0027	-11
1.0012	+13	1.0017	+5	1.0023	-5	1.0028	-13
1.0013	+11	1.0018	+3	1.0024	-6	1.0029	-14
1.0014	+10	1.0019	+2	1.0025	-8	1.0030	-16
		1.0020	0				

APPENDIX 1

SUMMARY OF EQUATIONS AND CONSTANTS USED IN THE COMPUTATION OF PERFORMANCE

1(a) Equations used in the calculation of performance results

Pump efficiency $\eta = \dfrac{\text{water horsepower}}{\text{horsepower to pump shaft}}$

$$= \frac{whp}{P} \times 100 \text{ per cent}$$

Water horsepower $whp = \dfrac{\gamma' Q\, H}{550}$ horsepower

Brake horsepower to pump shaft $P = \dfrac{2\pi NT}{33\,000} = \dfrac{NT}{5252.1}$ horsepower

Flowrate $Q = \dfrac{s\,W}{t}$ cusecs

Discharge Head $H_d = \left[KW_2 + C\right] \times \dfrac{144}{\gamma_p}$ ft H_2O

Suction Head $H_i = \dfrac{\gamma_m}{\gamma_p}\left[Hi_1 + Hi_2 + Hi_3\right]$ ft H_2O

where Hi_1, Hi_2 and Hi_3 are the heads measured by the suction manometers corrected for zero and the area ratio (see section 4.3.1)

Velocity Head $h_v = \dfrac{\bar{V}^2}{2g}$ ft H_2O

Total Pump Head $H = H_d + H_v - H_i$ ft H_2O

where $H_v = h_v$ discharge $- h_v$ inlet $= h_{vd} - h_{vi}$

Torque $T = C_L \left\{ \dfrac{0.5}{V} \left[\left(mV + mV_R \cdot \dfrac{N_1^{\,2}}{N_R^{\,2}} \right)\right] - \dfrac{mV_o}{V_o} \right\} + 188.0$ lb ft

Normal Affinity Laws

$$Q_3 = \left(\frac{2750}{N_1}\right) Q_1 \;; \qquad H_3 = \left(\frac{2750}{N_1}\right)^2 H_1 \;; \qquad P_3 = \left(\frac{2750}{N_1}\right)^3 P_1$$

1(b) Equations used in the calculation of cavitation results

<u>New Positive Suction Head:</u>

$$NPSH = H_i + h_{vi} + H_a - H_{v_p} \quad \text{ft } H_2O$$

<u>Speed Corrected NPSH:</u>

$$(NPSH)_2 = NPSH \left(\frac{2750}{N_1}\right)^2 \quad \text{ft } H_2O$$

<u>Pump Total Head corrected for Speed and Flow:</u>

$$H_{2_c} = H_2 + \frac{\delta H}{\delta Q} \Delta Q \quad \text{ft } H_2O$$

<u>Cavitation Coefficient:</u>

$$\sigma = \frac{(NPSH)_2}{\frac{1}{4} H_{2_c}}$$

<u>Suction Specific Speed:</u>

$$S = \frac{N(Q \text{ US gal/min})^{\frac{1}{2}}}{(NPSH)_2^{\frac{3}{4}}}$$

1(c) Values of Constants used in Calculations

Acceleration due to gravity: $g - 32.2031$ ft/sec^2

Area of suction measuring section As (to be checked before each bidders model tests). This constant will be provided on a separate record sheet to the observers.

Area of discharge measuring section Ad (to be checked before each bidders model tests). This constant will be provided on a separate record sheet to the observers.

Area ratio of suction manometers (see also Appendix 1(d))

K_{area_1} = 1.00209 (ref: KA1/20/4/67)

K_{area_2} = 1.00227 (ref: KA2/28/4/67)

K_{area_3} = 1.00230 (ref: KA3/24/4/67)

Conversion factor: 1 cusec = 490 US gal/min

The calibration of the torque tubes will be checked before each test; previous tests show that the C_L values for the 10 000 lb ft and 4000 lb ft torque tubes have remained close to 4924 and 2039.

The piston gauge manometers will also be checked, in this case nightly during the tests. In response to a request at the Observers Briefing Meeting values of diameters and weights will be given to observers for rough calculations only. These values will not be used for the official calculations for the bidders model tests.

1(d) Determination of Area Ratios of Single Limb Manometers

During the period reserved for overhauling and calibrating the instrumentation, prior to the commencement of the bidders models tests, the single limb manometers were dismantled and cleaned. Measurements of the internal diameter of the base and the Perspex tube were taken but due to the narrow bore of the tube it was only possible to obtain an accurate measurement at its extremities. The manufacture of the Perspex tube is such that uniformity of bore size cannot be guaranteed over the length of 80 inches required for the manometers. Thus the determination of the area ratio between the base and the tube could not be accurately determined simply from the measurements described above.

In order that the area ratio might be accurately determined the following method was employed:

The top of the base of the manometer was bored to take a Perspex gauge and assembly as shown in Fig. 45. The base of the Perspex was machined to the form of a cone and a circle was scribed on the machined area some $\frac{1}{4}$ inch from the apex, while the top of the Perspex gauge was machined to a flat surface. By means of the screwed coupling the gauge could be raised or lowered to suit.

In use, a manometer was coupled to a small hydraulic pump and a cathetometer was set up a short distance from the Perspex gauge. The centre line on the graticule of the cathetometer was used throughout and this was lined up on the flat surface of the Perspex gauge.

With no external pressure applied, the manometer zero was obtained after the gauge was screwed down until the scribed circle coincided with the meniscus of the mercury which formed around the conical end of the gauge. The reading on the manometer scale was taken and the cathetometer was adjusted, as described above. A reading was obtained from the scale on the cathetometer giving the gauge level corresponding to the manometer zero, i.e. the level of the mercury in the base corresponding to the manometer zero.

Pressure was then applied to the manometer by means of the hydraulic pump, thus raising a column of mercury up the limb of the manometer. The manometer taps were closed to prevent leakage through the pump, the gauge was adjusted and the manometer and cathetometer readings were taken, as before.

This procedure was repeated two or three times using approximately the same external pressure and to complete the test three or four different values of pressure were examined.

The results for each of the three manometers are shown in Appendix 1(c), the mean value of K_{area} for each manometer being obtained by using the mean value of R in the final equation:

$$K_{area} = 1 + \frac{1}{R}$$

where R is the ratio between the rise in level of mercury in the Perspex manometer tube and the corresponding fall in level of mercury in the reservoir base of the manometer.

APPENDIX 2

DANIEL MANN JOHNSON AND MENDENHALL

CONSULTANTS TO DEPARTMENT OF WATER RESOURCES, CALIFORNIA

Tehachapi Bidders Model Tests

Visitor's Statement

I have been delegated as a visitor to this test on behalf of:

(Firm's name)

1. I have received copies of the DMJM Specification No 637-1-2 and the NEL Laboratory Procedure Report for the Tehachapi Bidders Model Tests for my own information on , 1967.

2. I attended the Observer's Briefing Meeting on 1st to 22nd April, 1967 and the test installation and test procedures were explained to me by the NEL staff and the instrumentation and calibrations were demonstrated. The opportunity was given to me to clarify any points in question.

3. On a demonstration test run was performed where I had an opportunity to observe the actual test procedure and operation and I record here my satisfaction with the way those tests are performed.

4. I have been kept informed of the events on the pump test in a general way.

Because of the security requirements involved, which are known to me and which I shall fully observe, I did not have access to the test areas during the official tests nor to any data or calculations thereof. Should any data from these tests come to my knowledge I shall report this fact to the Chief of Test immediately but will not reveal this knowledge to anyone else.

....
Signed on arrival

Date ....

....
Resigned on departure

Date ....

(NOTE: A line is to be drawn through any statements, 1 to 4, that are not appropriate).

APPENDIX 3(a)

FORM OF ACCEPTANCE: PERFORMANCE AT 1500 REV/MIN
LABORATORY RAW DATA

DANIEL, MANN, JOHNSON, & MENDENHALL
CONSULTANTS TO DEPARTMENT OF WATER RESOURCES, CALIFORNIA

Tehachapi Bidders Model Tests

1500 rev/min Test Data

for the

4-stage Model Pump

by

Contractor: ____

Model No: ____

This statement is made out in three copies, which will be distributed as follows:

Original to DMJM.

Copy No 1 to NEL.

Copy No 2 to the Contractor.

Three copies of the calculated results will be produced subsequently and after review. Copies 1 and 2 will be retained in the NEL safe and Copy 3 will be given to the Contractor. Copy 1 will be available for DMJM/MC use at NEL and will be released to DMJM/MC after the bid opening.

Date of Signature: ______________________________
Signed at the National Engineering Laboratory,
East Kilbride, Glasgow.

A. Summary of Test Result

The model pump arrived at the Laboratory on ____________ ____________________, 1967. A commissioning test at 1500 rev/min was carried out on ______________________________________ ____, 1967.

The performance tests at 1500 rev/min were conducted on ____, 1967.

All test work was performed in accordance with Specification No 637-1-2 and amendments, and following the 'NEL Laboratory Procedure Report for the Tehachapi Bidders Model Tests'.

East Kilbride, GLASGOW, (Date) ______________________

Signature ______________________

Name ______________________

Chief of Test

National Engineering Laboratory

B. Contractors Acceptance

On behalf of ______________________
I am authorized to confirm:

I and my staff have checked the test set-up, the model pump mounting and the instrumentation and found all in proper working condition. I and my staff have witnessed all instrument calibration, checked the readings of the Laboratory's staff during test by random selection, and signed the calibration and data sheets. To the best of my knowledge the tests were performed in a proper way and according to Specification No 637-1-2 and amendments and the 'NEL Laboratory Procedure Report for the Tehachapi Bidders Model Tests'.

East Kilbride, GLASGOW, (Date) ______________________

Signature: ______________________

Name: ______________________

Position: ______________________

Firm: ______________________

C. Engineers Statement

On behalf of Daniel, Mann, Johnson, & Mendenhall, Consulting Engineers of Los Angeles, California, and Motor Columbus Ltd., Consulting Engineers of Baden, Switzerland, who have conducted this test on behalf of the Department of Water Resources, State of California, I confirm that I and my staff have observed the testing and that to the best of my knowledge it was conducted in accordance with Specification No 637-1-2 and amendments, and with the 'NEL Laboratory Procedure Report for the Tehachapi Bidders Model Tests'.

East Kilbride, GLASGOW, (Date) ______________________

Signature: ______________________

Name: ______________________

Position: ______________________

Firm: ______________________

APPENDIX 3(b)

FORM OF ACCEPTANCE: PERFORMANCE AT 2250 REV/MIN
LABORATORY RAW DATA AND CALCULATIONS ACCEPTANCE

DANIEL, MANN, JOHNSON, & MENDENHALL
CONSULTANTS TO DEPARTMENT OF WATER RESOURCES, CALIFORNIA

Tehachapi Bidders Model Tests

Statement of 2250 rev/min Test Results and Acceptance Thereof

for the

4-stage Model Pump

by

Contractor: ____________________

Model No: ____________________

This statement is made out in three copies, which will be distributed as follows:

Original to DMJM

Copy No 1 to NEL

Copy No 2 to the Contractor.

Calculated results will be produced in three copies and distributed as follows:

Copy 1 for DMJM/MC to be retained in the NEL safe until after the bid opening. DMJM/MC will have access to the results on NEL permission.

Copy 2 to NEL

Copy 3 to the Contractor.

Date of Signature: ____________________
Signed at the National Engineering Laboratory,
East Kilbride, Glasgow.

A. Summary of Test Result

The model pump arrived at the Laboratory on ____________________, 1967. A commissioning test at 1500 rev/min was carried out on ____________________ 1967 and at 1500 rev/min a performance test was carried out on ____________________, 1967.

The performance tests at 2250 rev/min were conducted on ____________________, 1967. All test work was performed in accordance with Specification No 637-1-2 and amendments, and following the 'NEL Laboratory Procedure Report for the Tehachapi Bidders Model Tests'. The calculated results are given on computer print-out ______________________.

East Kilbride, GLASGOW, (Date) ______________________

Signature ______________________

Name ______________________

Chief of Test

National Engineering Laboratory

B. Contractors Acceptance

On behalf of ______________________
I am authorized to confirm:

I and my staff have checked the test set-up, the model pump mounting and the instrumentation and found all in proper working condition. I and my staff have witnessed all instrument calibration, checked the readings of the Laboratory's staff during test by random selection, and signed the calibration and data sheets. To the best of my knowledge the tests were performed in a proper way and according to Specification No 637-1-2 and amendments and the 'NEL Laboratory Procedure Report for the Tehachapi Bidders Model Tests'.

The computer print-out of the 2250 rev/min performance test was given to me on ______________________, 1967. I have checked the computer input data against the raw data sheets, and the computer calculation of the test results and found it to be correct.

I accept the computed results given on print-out ______________ as being correct. I understand that DMJM/MC reserve the right to use these results for purposes of the bid evaluation in the event it is not possible to obtain sufficient data for all models at the 2750 rev/min test speed. I also understand that if these data are used in the bid evaluation I will be so notified and I will select and declare the final value of the model to prototype scale ratio D^1/D, and accept the 'stepped-up' prototype efficiency value for the bid evaluation within a period of five days - the 'step-up' formula given in the prototype specification will be used with the 2250 rev/min model efficiency.

East Kilbride, GLASGOW, (Date) ______________________

Signature: ______________________

Name: ______________________

Position: ______________________

Firm: ______________________

C. Engineers Statement

On behalf of Daniel, Mann, Johnson, & Mendenhall, Consulting Engineers of Los Angeles, California, and Motor Columbus Ltd., Consulting Engineers of Baden Switzerland, who have conducted this test on behalf of the Department of Water Resources, State of California, I confirm that I and my staff have observed the testing and the evaluation of the test results, and that to the best of my knowledge these were conducted in accordance with Specification No 637-1-2 and amendments, and with the 'NEL Laboratory Procedure Report for the Tehachapi Bidders Model Tests'. In the event the 2750 rev/min results are not complete for all models, I will notify the Contractor that these results will be used in the bid evaluation according to the rules established for the 'Official' tests and results.

East Kilbride, GLASGOW, (Date)____________________

Signature:____________________

Name:____________________

Position:____________________

Firm:____________________

APPENDIX 3(c)

FORM OF ACCEPTANCE: PERFORMANCE AT 2750 REV/MIN

DANIEL, MANN, JOHNSON, & MENDENHALL
CONSULTANTS TO DEPARTMENT OF WATER RESOURCES, CALIFORNIA

Tehachapi Bidders Model Tests

Statement of Test Results and Acceptance Thereof

for the

4-stage Model Pump

by

Contractor: ______________________________

Model No: ______________________________

This statement is made out in three copies, which will be distributed as follows:

Original to DMJM, to be handed over to the State of California's official representative at the time of bid opening

Copy No 1 to NEL

Copy No 2 to the Contractor.

Date of Signature: ____________________
Signed at the National Engineering Laboratory,
East Kilbride, Glasgow.

A. Summary of Test Result

The model pump arrived at the Laboratory on ______________ ______________, 1967. A commissioning test at 1500 rev/min was carried out on ______________, 1967, followed by a performance test at 1500 rev/min on ______________, 1967, followed by a second performance test at 2250 rev/min on ______________ ______________, 1967.

The official performance tests at 2750 rev/min were conducted on ______________, 1967, with cavitation tests on ______________, 1967. All test work was performed in accordance with Specification No 637-1-2 and amendments, and following the 'NEL Laboratory Procedure Report for the Tehachapi Bidders Model Tests'.

The model was found to comply with the specified cavitation requirements. The test data measurements of the official performance tests were computed according to the specification and showed the following result.

The Q-H characteristic complies with the requirements set forth in the specification. The best model efficiency within the specified range is ______________ per cent. Stepped-up as specified with a model/prototype scale ratio of ______________________________, as finally selected by the contractor, the stepped-up prototype efficiency to be used in the bid evaluation is

________________________________ per cent

A detailed test report will be submitted to DMJM on behalf of DWR one month after the bid opening.

East Kilbride, GLASGOW, (Date) ______________________________

____
Name
Chief of Test
National Engineering Laboratory

B. Contractors Acceptance

On behalf of ______________________________
I am authorized to confirm:

I and my staff have checked the test set-up, the model pump mounting and the instrumentation and found all in proper working condition. I and my staff have witnessed all instrument calibration, checked the readings of the Laboratory's staff during test by random selection, and signed the calibration and data sheets. To the best of my knowledge the tests were performed in a proper way and according to Specification No 637-1-2 and amendments and the 'NEL Laboratory Procedure Report for the Tehachapi Bidders Model Tests'.

The computer print-out of the official performance test was given to me on ____________________________, 1967. I have checked the computer input data against the raw data sheets, and the computer calculation of the test results and found it to be correct. The final selection of the model/prototype scale ratio has been made and the value is: D^1/D = ______________________________.

Therefore, I accept the above mentioned stepped-up prototype efficiency of __________________________ per cent to be used in the bid evaluation.

East Kilbride, GLASGOW (Date)______________________________

Signature:______________________________

Name:______________________________

Position:______________________________

Firm:______________________________

C. Engineers Statement

On behalf of Daniel, Mann, Johnson, & Mendenhall, Consulting Engineers of Los Angeles, California, and Motor Columbus Ltd., Consulting Engineers of Baden, Switzerland, who have conducted this test on behalf of the Department of Water Resources, State of California, I confirm that I and my staff have observed the testing and the evaluation of the test results, and that to the best of my knowledge these were conducted in accordance with Specification No 637-1-2 and amendments, and with the 'NEL Laboratory Procedure Report for the Tehachapi Bidders Model Tests'. I shall hold this Statement of Test Result and Acceptance in Security and present it to the Department's official at the time and place of bid openings.

East Kilbride, GLASGOW, (Date) ______________________________

Signature: ______________________________

Name: ______________________________

Position: ______________________________

Firm: ______________________________

APPENDIX 4

LIST OF TESTS TO BE CHECKED BY OBSERVERS

The data from which the bidders model pumps will be evaluated will be obtained from calibrations as well as from measurements made during actual pump tests. It is essential that both Observers and Manufacturers Representatives witness all relevant sources of data, and initial the appropriate data sheets. Given below is a comprehensive list of such sources.

1. Preparatory (March to May 1967)

   (i) Weightank calibration

   (ii) Comparison of deadweight tester, piston gauge manometer and single limb manometer

   (iii) Determination of effective area ratios of single limb manometers

   (iv) Calibration of thermometers

The above will be repeated as soon as possible after the finish of the tests on the last bidders model.

2. Test period

   (i) Measuring section pipe diameters (to be checked during installation of each bidders model)

   (ii) Calibration of torque tubes (between 8.30 a.m. and 5 p.m. before and after each test series with repeat checks between if necessary)

   (iii) Specific gravity of sump water (between 8.30 a.m. and 12 noon daily during tests)

   (iv) Calibration of piston gauge manometer (between 8 p.m. and 9 p.m. nightly during tests)

   (v) Zero reading of single limb manometers (immediately before and after each night's test)

   (vi) Pre-set arm torque readings (immediately before and after each night's test)

   (vii) Test data (data recorded by the various stations during pump tests).

APPENDIX 5: NOTATION

SYMBOL	DEFINITION	UNITS	FIRST APPEARANCE
	Torque measurement		
T	Torque to pump shaft	lb.ft	4.2.6
C_L	Constant in static torque calibration	–	
mV	Average torque reading during flow diversion referred to 10mV range	millivolts	
V	Bridge voltage corresponding to mV reading	volts	
mV_R	Average torque reading (10mV range) with bridge voltage reversed	millivolts	
V_R	Reversed bridge volts corresponding to mV_R reading	volts	
mV_o	Average torque reading (10mV range) with pre-setting arm balanced	millivolts	
V_o	Bridge voltage corresponding to mV_o reading	volts	
	Velocity head measurement		
$\bar{V}$	Mean velocity in measuring section	ft/sec	4.3
Q	Flowrate through pump at temperature θ_p	ft³/sec	
A	Cross-sectional areas of measuring section at suction and discharge	ft²	
g	Acceleration due to gravity	ft/sec²	
h_{vd}	Velocity head at discharge measuring section	ft	
h_{vi}	Velocity head at suction measuring section		
θ_p	Temperature of water just upstream of pump	°C	
	Suction head measurement		
K_{area}	Suction manometer, ratio of base area to tube area	–	4.3.1
ρ'_m	Effective density conversion factor for suction manometers	ft H_2O/in Hg.	
ρ'_{Hg}	Density of mercury at the manometer temperature θ'_m	lb/ft³	
$(s.g.)$	Specific gravity of water in sump as ratio to distilled water	–	
ρ'_w	Density of distilled water at the manometer temperature	lb/ft³	
θ'_m	Temperature of air in proximity to suction manometer	°C	
	Discharge head measurement		
H_d	Head at discharge measuring section	ft H_2O	4.3.2
γ_p	Specific weight of water pumped, at temperature	lb/ft³	
K	Calibration constant for piston gauge manometer	in⁻²	
W_2	Weights added to piston gauge manometer	lb	
C	Calibration constant for piston gauge manometer	lb/in²	
h_m	Manometer level reading on piston gauge manometer	in	

SYMBOL	DEFINITION	UNITS	FIRST APPEARANCE
	Flow measurement		
W	Weight of water diverted	lb	4.4.8
t	Time of diversion	sec	
γ'	Specific weight of distilled water at θ_p	lb/ft^3	
S	Correction for buoyancy, specific weight of water and specific gravity	–	
D	Prototype impeller diameter	ft	
D^1	Model impeller diameter	ft	6.1
	General		6.1
(D'/D)	Manufacturers preliminary scale factor	–	6.1
Q_0'	Model flowrate at rated conditions	ft^3/sec	"
NPSH	Net positive suction head	ft	"
H_i	Suction inlet head at pump	ft	6.4.1
H	Pump total head	ft	7.1
P	Brake horsepower to pump shaft	hp	"
N	Rotational speed of pump shaft	rev/min	7.2
η	Pump efficiency	–	"
H_v	Velocity head difference between suction and discharge measuring sections	ft	"
H_a	Barometric pressure head	ft	7.3
H_{vp}	Vapour pressure of water at θ_p	ft	
σ	Cavitation coefficient	–	"
S	Suction specific speed	–	"
N_s	Specific speed of pump	–	"

NOTE: 1

Notation used in the computer programme will be listed separately in Appendix 6.

NOTE: 2

Where additional subscripts are used in the test these are defined at that point. For example the subscript 2 is used with H, N, NPSH etc., to indicate an intermediate step in the calculations in the computer programme where the raw data is corrected to a specified average speed for the night's run: for the official tests at 2750 rev/min, this speed is also adopted for N_2.

APPENDIX 6

The missing Appendix will be issued separately
as a supplement to the Laboratory Procedure Report

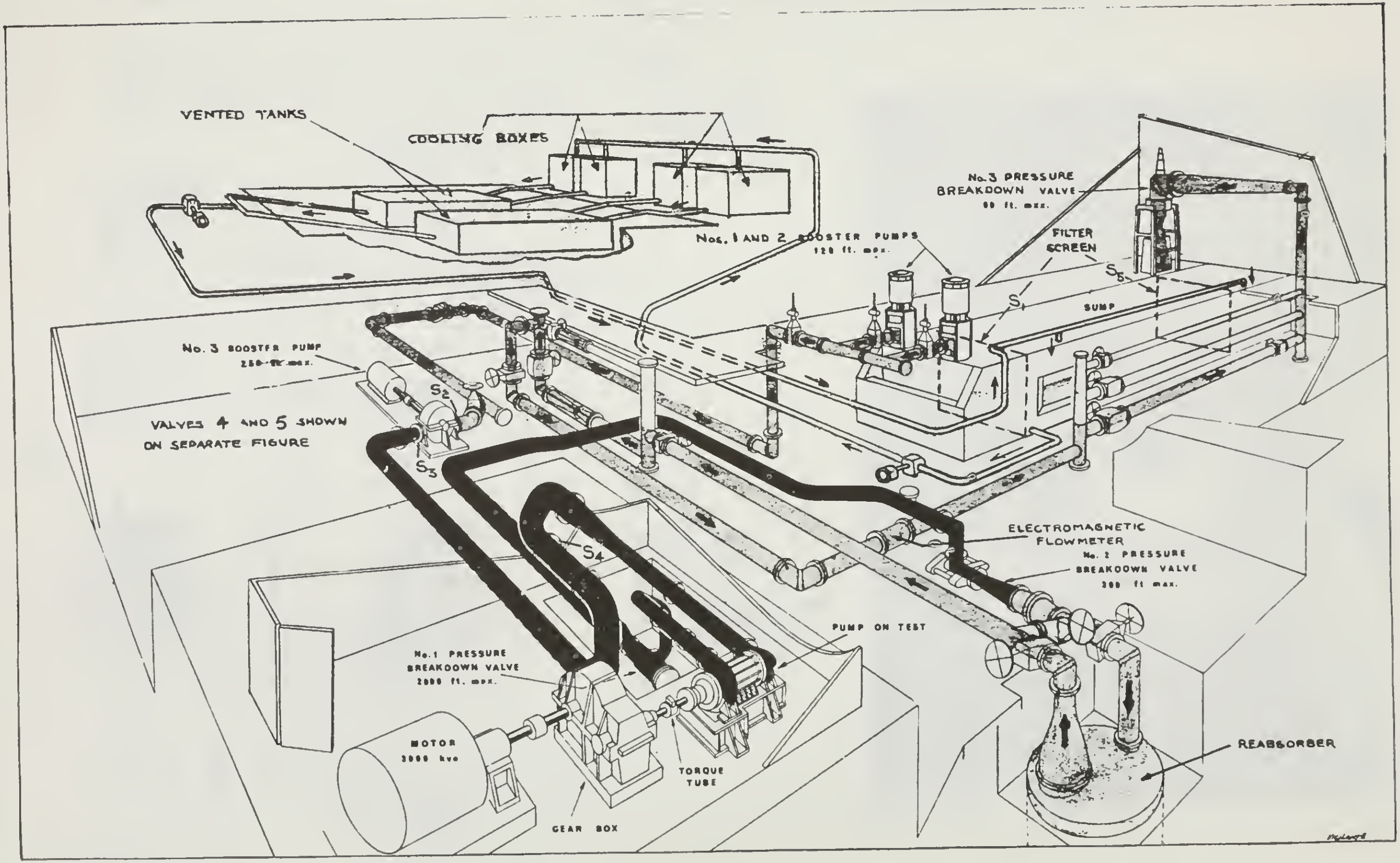


FIG. 1(a). HIGH POWER PUMP TEST RIG

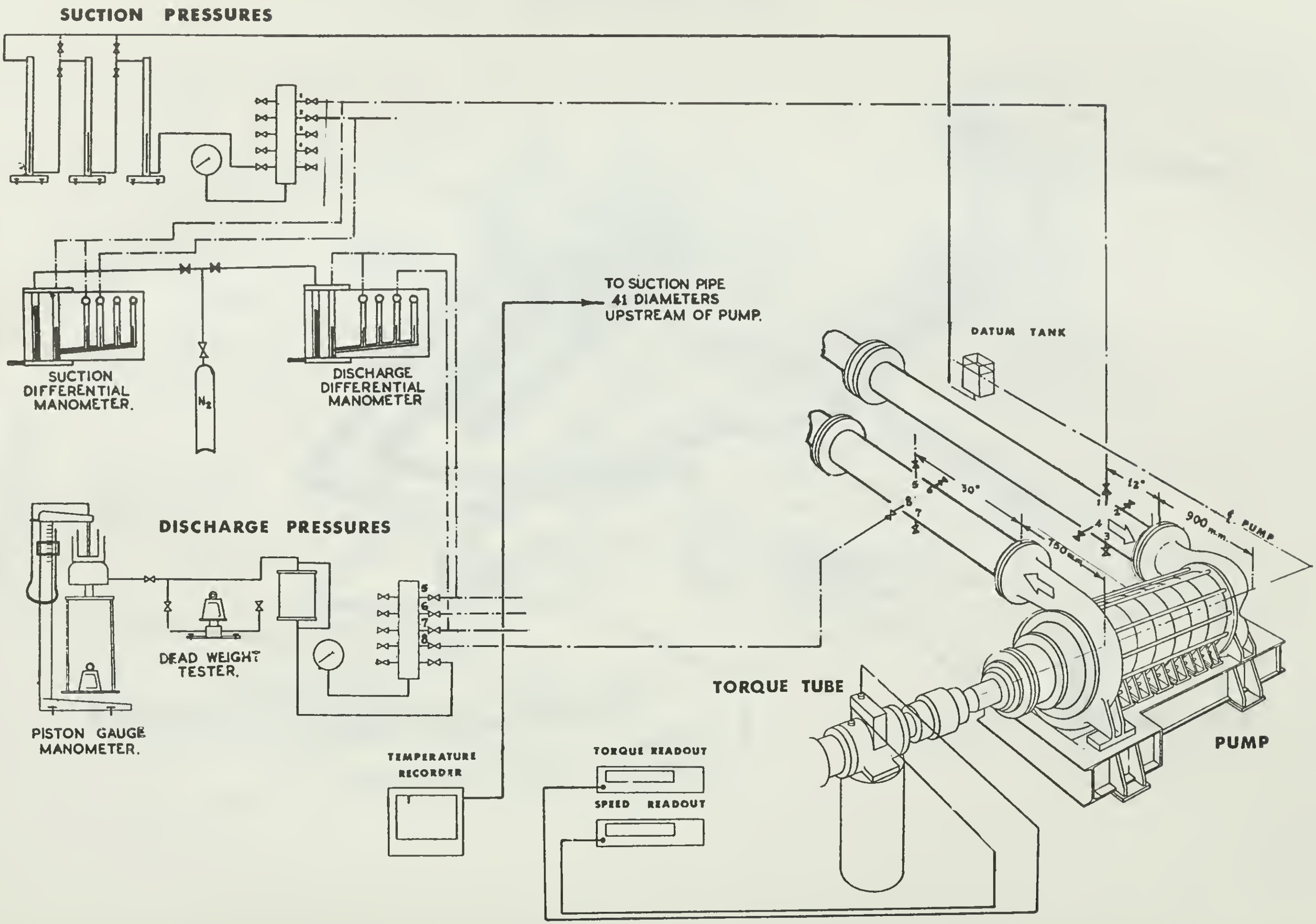


FIG. 1(b). TEST RIG AND INSTRUMENTATION

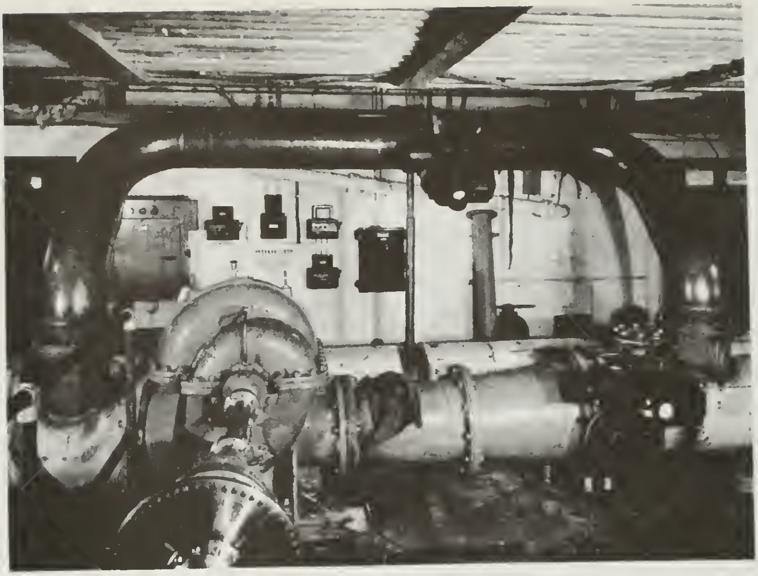


FIG. 2(a). BYPASS AND No 3 BOOSTER PUMP

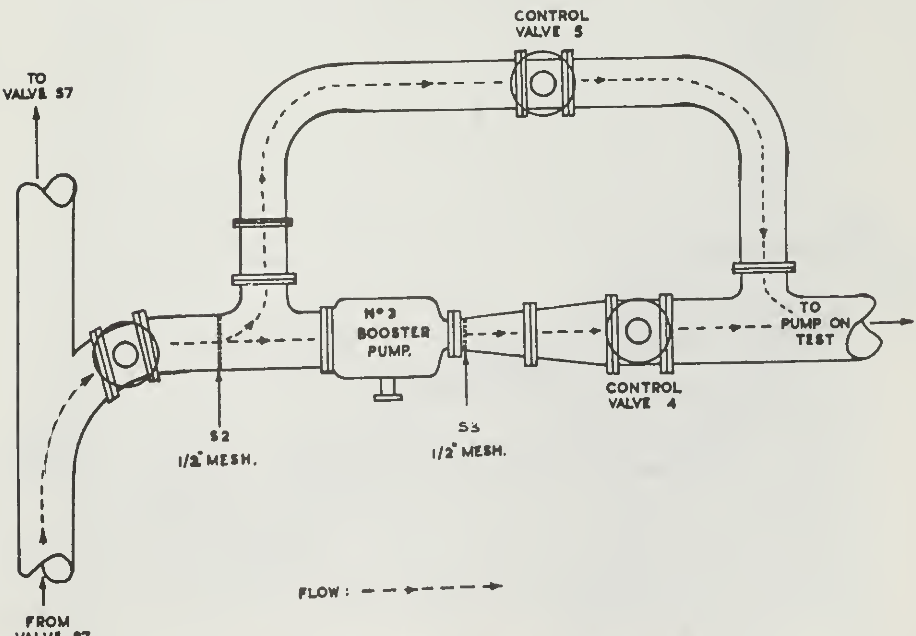


FIG 2 (b) LINE DIAGRAM SHOWING PIPING ARRANGEMENT AT N° 3 BOOSTER PUMP

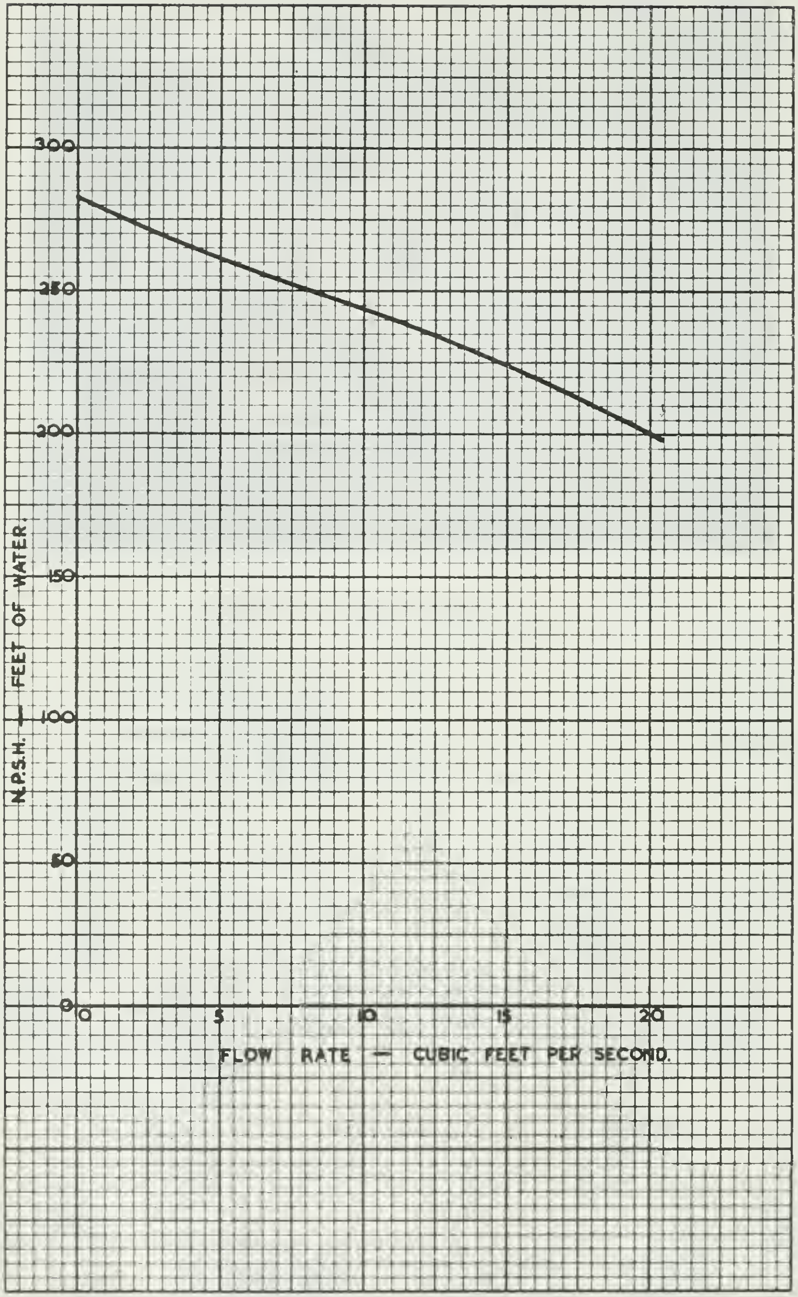


FIG 3 MAXIMUM AVAILABLE N.P.S.H.

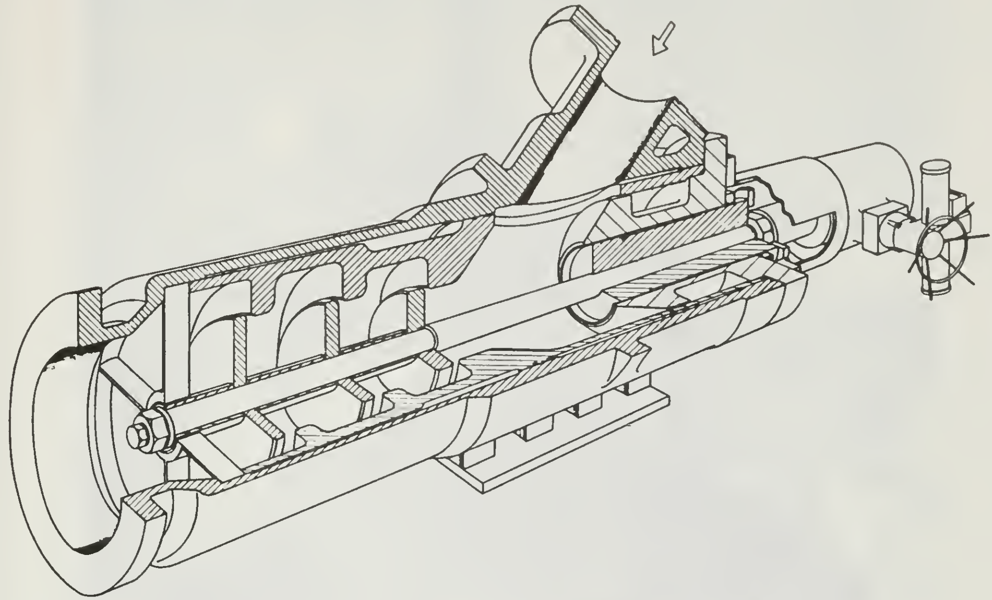


FIG. 4. DARLING VALVE - No 1 BREAKDOWN VALVE

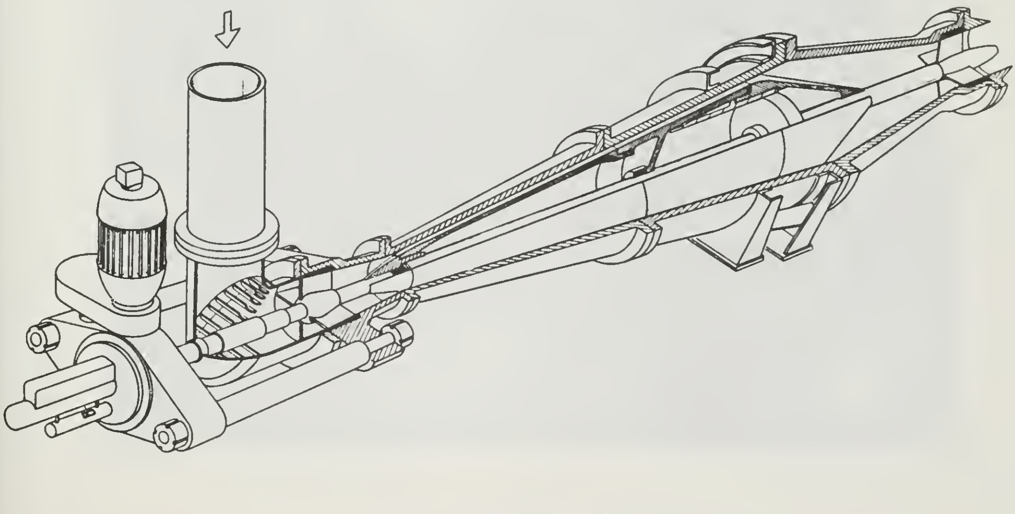


FIG. 5. VALVE 76 - No 2 BREAKDOWN VALVE

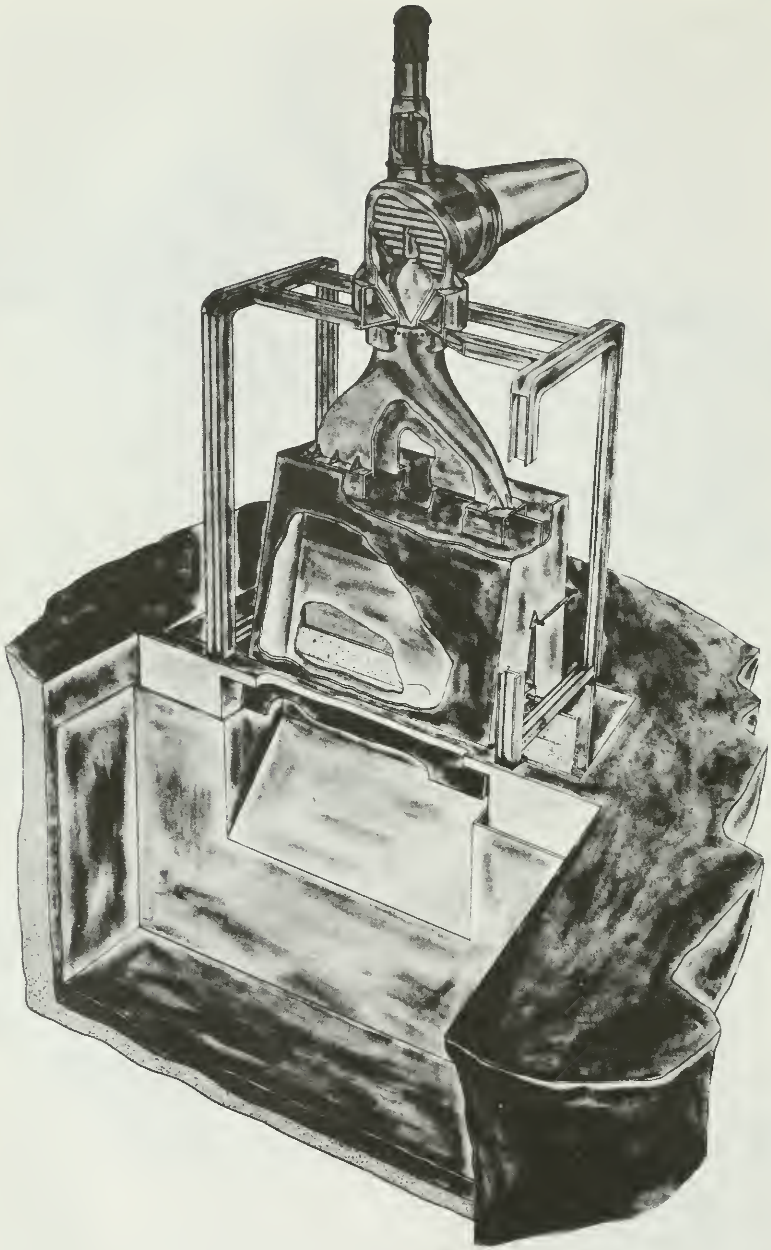


FIG. 6 SPEAR VALVE - No 3 BREAKDOWN VALVE AND DIVERTER

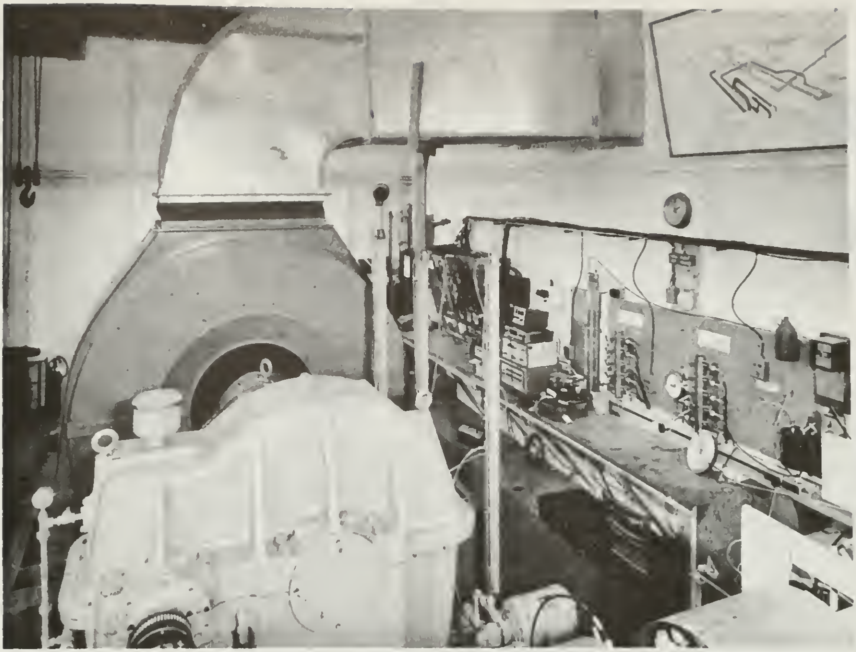


FIG. 7. 4000 HP MOTOR AND GEARBOX

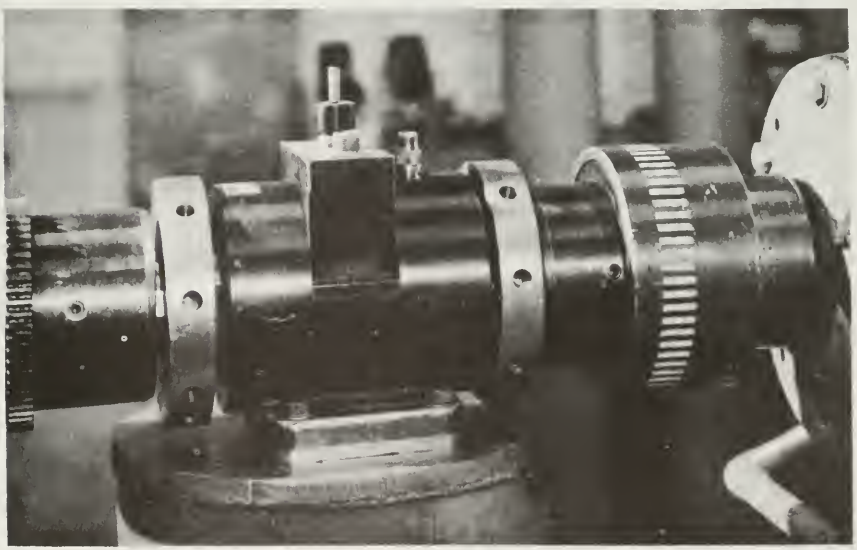


FIG. 8. TORQUE TUBE

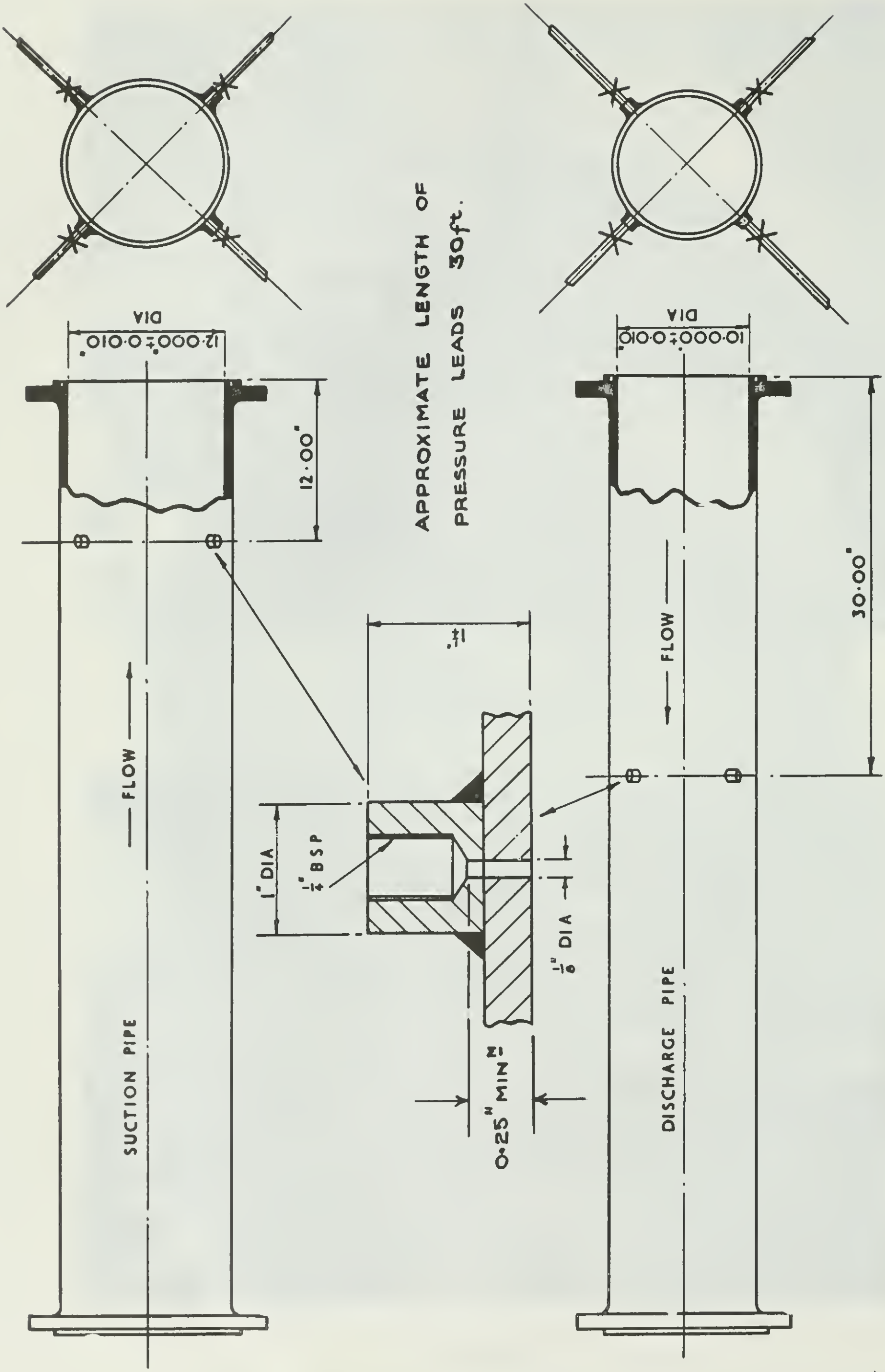


FIG 9 MEASURING SECTIONS

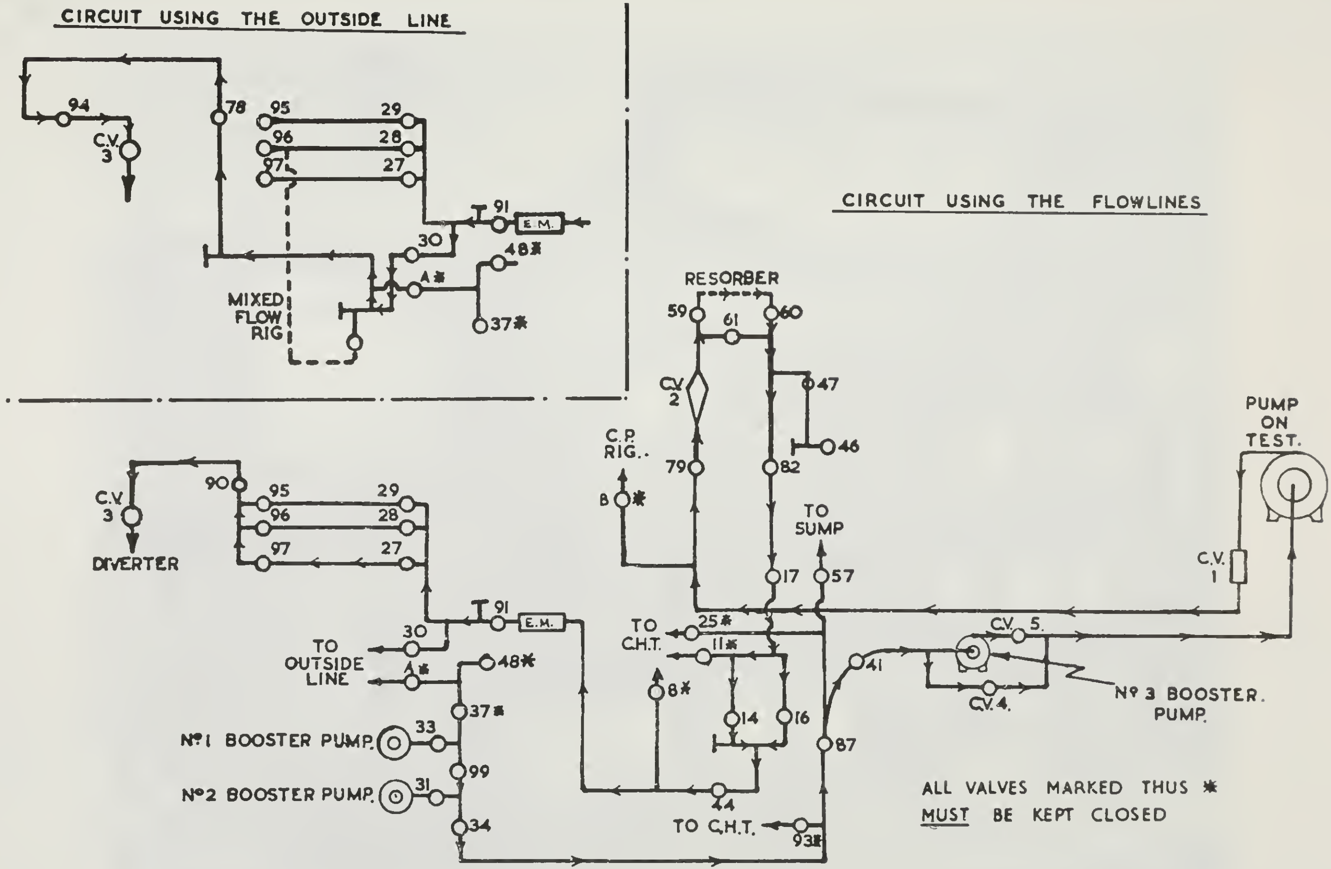


FIG 10 PRIMARY CIRCUIT DIAGRAM

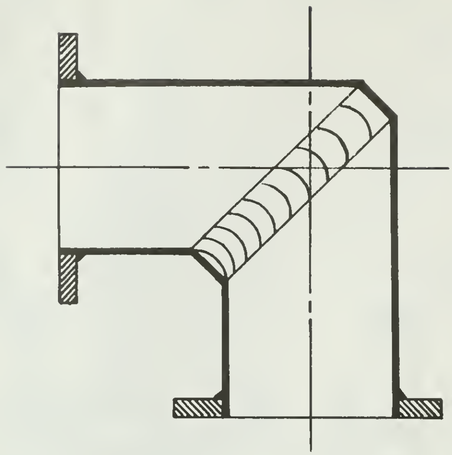


FIG 11 TYPICAL CASCADE BEND

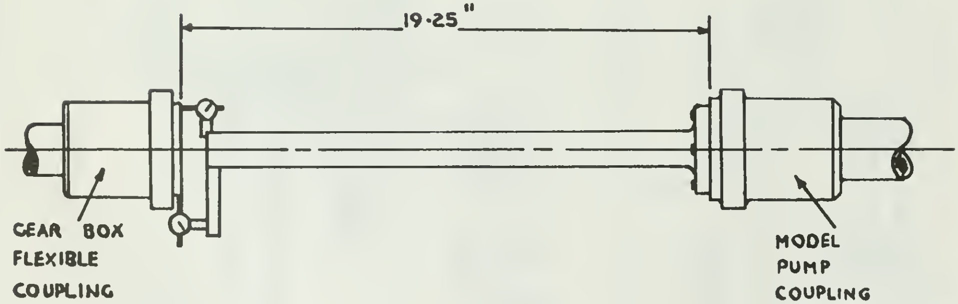


FIG 12 ALIGNMENT SHAFT

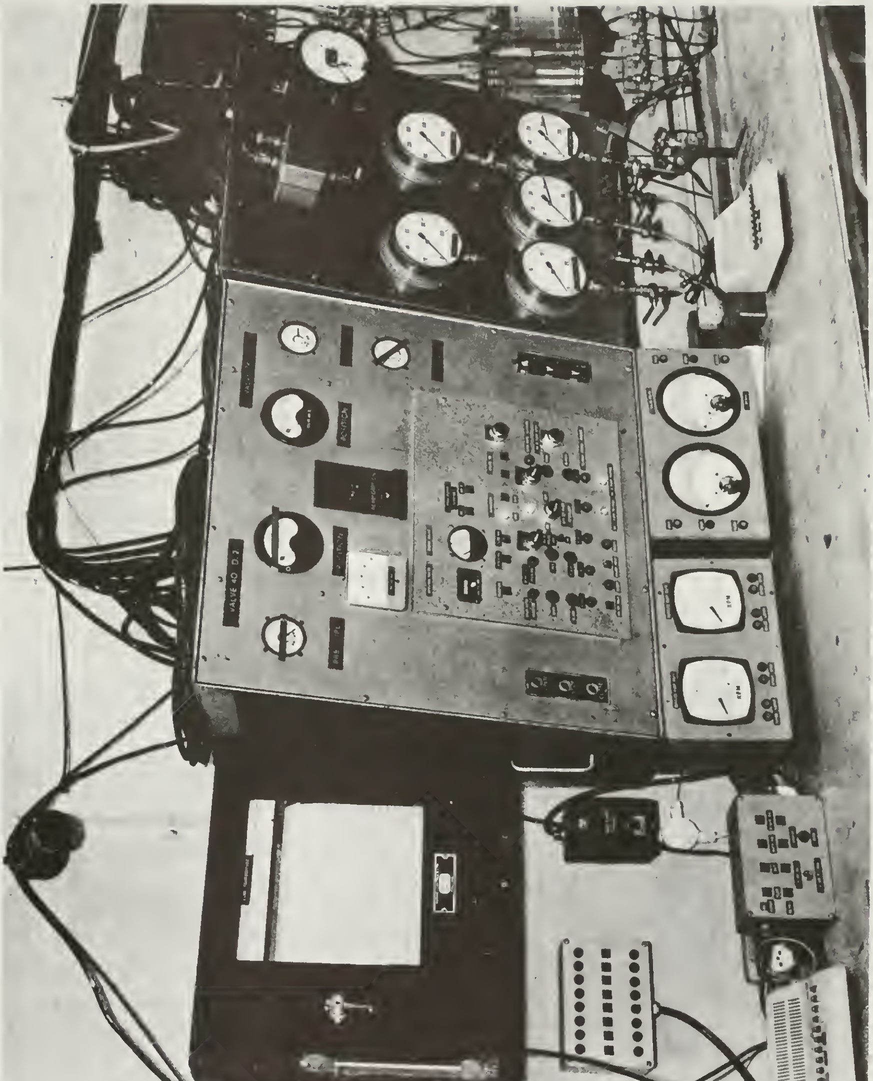


FIG. 13. VIEW OF CONTROL PANEL

TEST TEAM :- CONTROLLER..................
TORQUE & SPEED..................
SUCTION HEAD..................
DISCHARGE HEAD..................
FLOW..................
DATA COLLECTION..................
CARD PUNCHING..................

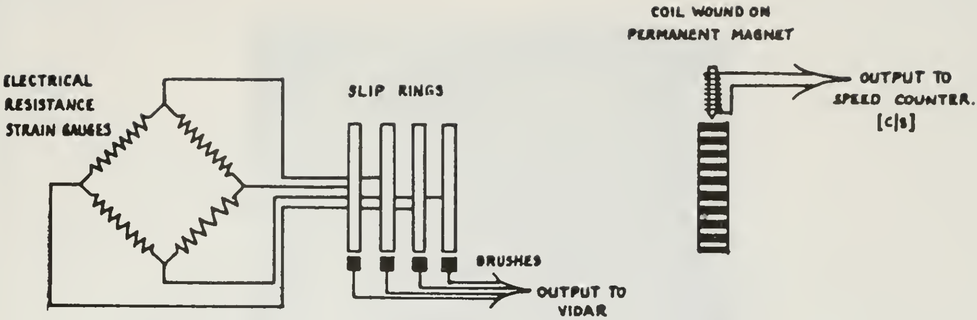
LABORATORY SERVICES :- M P B W ELECTRICIAN..................
LABORATORY MECHANIC..................

OBSERVERS :- N.E.L. CHIEF OF TESTS..................
D.M.J.M. REPRESENTATIVE..................
MANUFACTURER'S REPRESENTATIVE..................

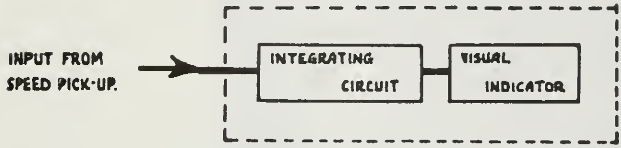
PUMP..................
NOMINAL SPEED..................
DATE..................
TORQUE TUBE..................

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
	FLOW		VALVE SETTINGS					PRESSURE					SPEEDS					POWER				
RUN Nº	E.M. FLOWMETER (cusecs) TEST HOUSE	MAIN BAY	DARLING VALVE CONTROL VALVE Nº 1	VALVE 76 CONTROL VALVE Nº 2	SPEAR VALVE CONTROL VALVE Nº 3	BOOSTER THROTTLE CONTROL VALVE Nº 4	BY-PASS THROTTLE CONTROL VALVE Nº 5	PUMP SUCTION p.s.i.	PUMP DISCHARGE p.s.i.	DOWNSTREAM DARLING VALVE p.s.i.	DOWNSTREAM VALVE 76 p.s.i.	UPSTREAM SPEAR VALVE p.s.i.	MODEL rev/min	SERVICE PUMP Nº 1 rev/min	SERVICE PUMP Nº 2 rev/min	SERVICE PUMP Nº 3 rev/min	LINE TEMPERATURE °C	WATTMETER READING W_1	WATTMETER READING W_2	NUMBER OF COOLING TOWERS IN USE	TIME OF DAY	REMARKS

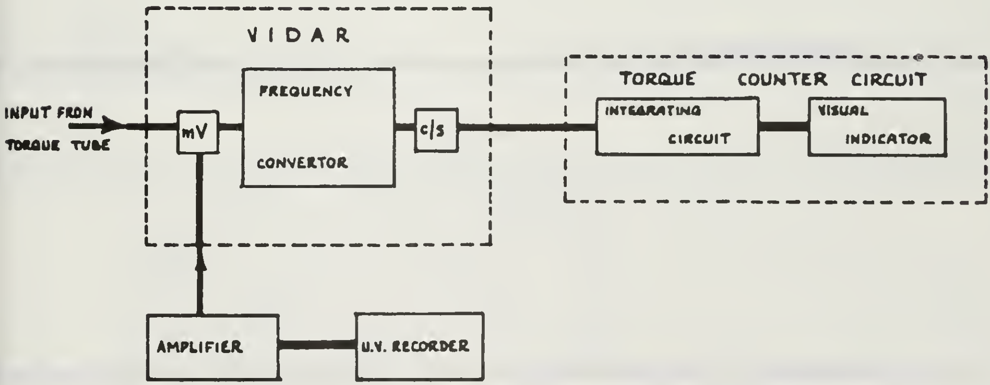
FIG 14 SPECIMEN DATA SHEET



TORQUE TUBE.



SPEED COUNTER CIRCUIT.



TORQUE OUTPUT CIRCUIT.

FIG. 15 LINE DIAGRAM OF TORQUE & SPEED MEASUREMENT SYSTEMS.

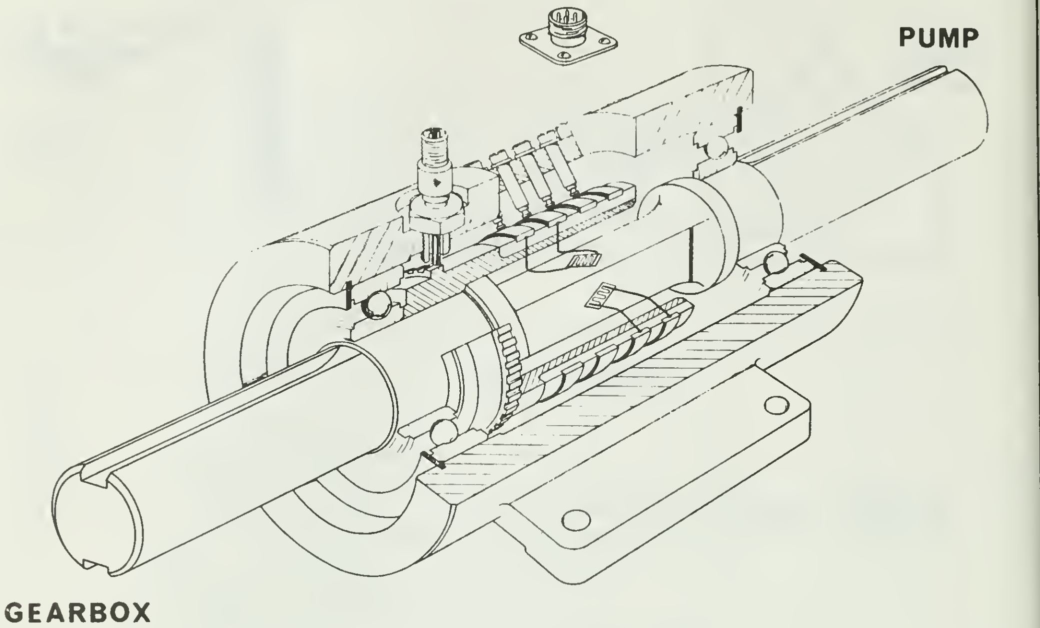


FIG. 16. LINE DIAGRAM OF TORQUE TUBE

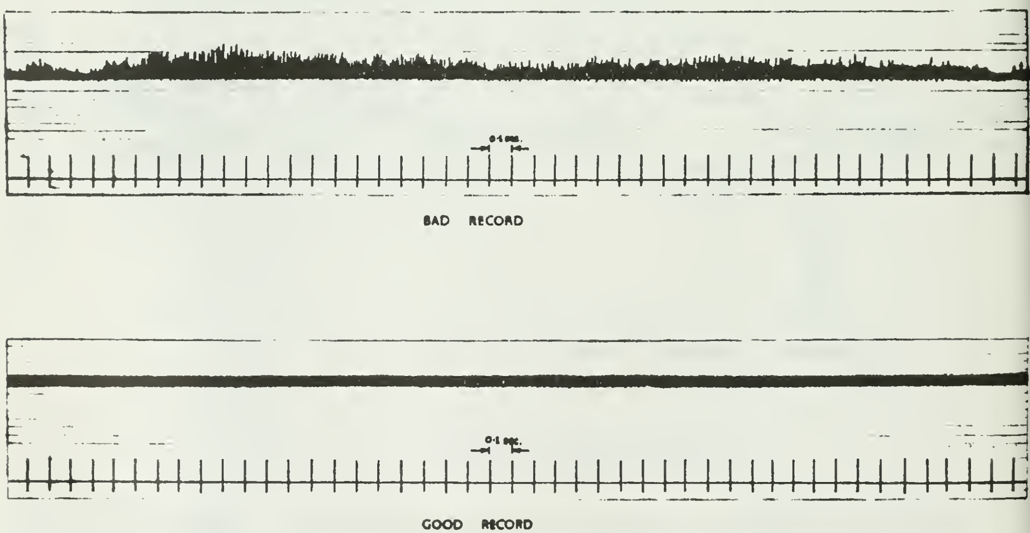


FIG 17 TYPICAL U.V. RECORDINGS

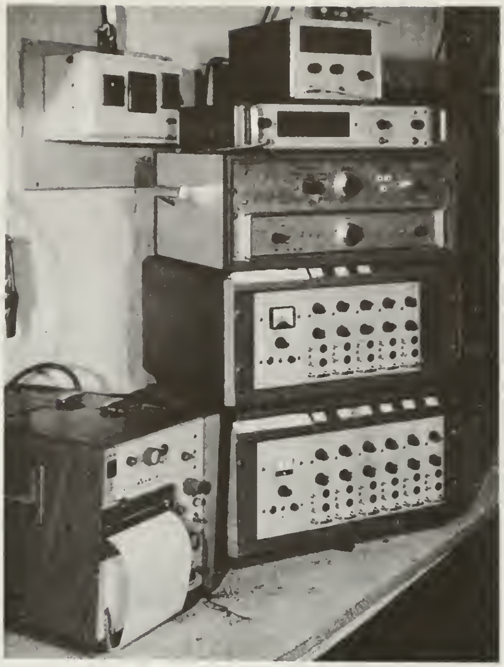


FIG. 18. VIEW OF TORQUE AND SPEED INSTRUMENTATION

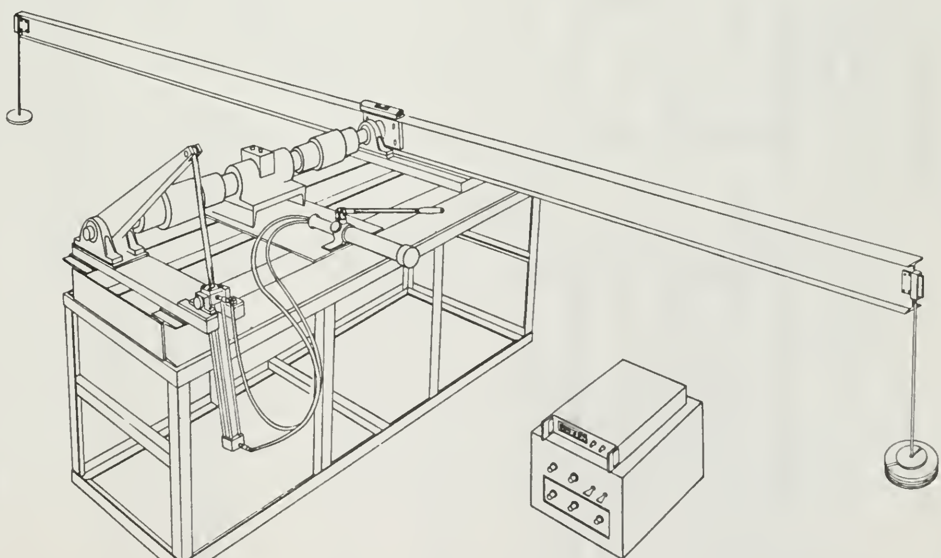


FIG. 19. TORQUE TUBE CALIBRATOR

DATE ____________ TEST RUN Nº ____________ N.E.L. OBSERVER ____________

SPEED [rev/min]	M I Nº OF READINGS	VOLT [mV]

R SPEED [rev/min]

R VOLT [mV]

RANGE [mV]

B VOLT [V]

Z1

Z2

CALIBRATION REF		

____________ PUMP

N.E.L. ____________

DMJM. ____________

MANUFACTURER ____________

FIG 20 SPECIMEN DATA SHEET (SPEED AND TORQUE)

TORQUE TUBE

Date: ... lb ft Lebow torque tube No Pump tested:

			Before test		After test	
			Without torque arm	With torque arm	Without torque arm	With torque arm
Instrument zero	mV range	5 mV				
		10 mV				
		20 mV				
		1000 mV				
Standard cell volts						
Bridge volts						
Torque zero/mV range						
Torque zero (bridge volts reversed)/mV range						
Time of day						

C_L =
as calculated from calibration carried out on

Reference No

NEL observer:

Other observer:

FIG. 21. SPECIMEN CALIBRATION SHEET FOR TORQUE TUBE

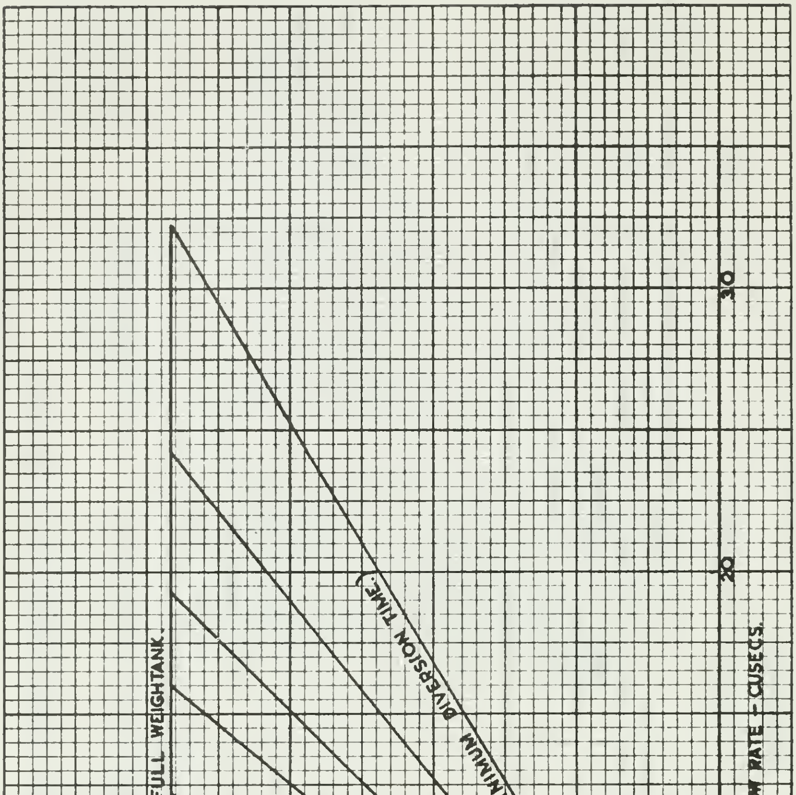


FIG 22 FALL IN SUMP LEVEL DUE TO FILLING WEIGHTANK

CERTIFICATE OF ACCURACY

FOR A

BUDENBERG DEAD-WEIGHT PRESSURE TESTER

Serial Number 3557

Catalogue Section 3, Fig. 280 L Dead-weight Pressure Gauge Tester

The piston and cylinder unit marked with Serial No. A.516 fitted to this tester has been balanced by us against an assembly calibrated by the National Physical Laboratory and the comparison enables us to certify that the error of this tester when used at standard temperature of 20°C±1°C (68°F±1·8°F) does not exceed 0.05% of the pressure being measured, provided that the tester has been used in conformity with the instructions supplied. We are authorised to state that the comparison procedure and the procedure for calibrating the loading weights, adopted by us has been inspected and approved by the National Physical Laboratory. (The tester construction is such that the gauge inlet is at the same level as the datum line of the dead-weight system. If the gauge is fixed at any other level an allowance must be made for the difference in head of oil).

SIGNED

DATE 9th September, 1966.

p.p. BUDENBERG GAUGE CO. LTD.

NOTES ON THE USE OF THIS TESTER

Since the markings of even a 10 inch dial standard test gauge cannot be read with certainty to less than **0·1% of the full scale reading** it follows that the accuracy of the tester is greater than that which is needed for the calibration of such a gauge.

If the user of this tester is concerned only with the calibration of dial gauges, no corrections will be necessary unless tests are being made at temperatures much below or above normal room temperatures, or the tester is being used at a place where the acceleration due to gravity differs markedly from the standard, i.e. anywhere outside the limits of 40° and 50° latitude or altitude or more than 3,000 feet above sea level.

If, however the user of the tester wishes to make tests with a greater degree of refinement than is normally required for testing dial pressure gauges, he will need to take the following additional factors into consideration:—

(1) Temperature Correction

If the temperature at which tests are being made differs from 68°F. the temperature error can be corrected by deducting 0·0015% from the nominal pressure for each 1°F. rise in temperature and adding correspondingly for each 1°F. fall.

(2) Effect of the acceleration due to gravity

The effect of the acceleration due to gravity on the pressures exerted by dead-weight testers is fully explained in British Standard Specification 1780: Pressure Gauges. Users are advised that the calibration for this tester is only exact at a place where the acceleration due to gravity is 980·665 cm/sec². If the tester is used at any other place the nominal pressure must be multiplied by $\frac{g}{980 \cdot 665}$ where g is the intensity of gravity, in cm/sec², at the place where the tester is being used.

(3) Change in effective area of piston and cylinder assembly under change of pressure

The greatest error that can be caused by this change is allowed for in this Certificate of Accuracy but if, for special reasons, figures for the change in area are considered essential, we can provide them on special request.

(4) Limitation at low pressures

At pressures below about 50 lb/in² the inertia of the weights is such that they cannot be rotated long enough for a true pressure balance to be established. For very accurate measurement of such pressures it is therefore desirable to use a tester with a larger piston and heavier weights. For this purpose our Fig. 240 Air-operated Dead-weight Tester (range 2-60 lb/in²) is very suitable.

BUDENBERG GAUGE CO. LTD. BROADHEATH, Near MANCHESTER.

FIG. 23. NPL CALIBRATION CERTIFICATE FOR DEADWEIGHT TESTER

DATE ______________ TEST RUN Nº ______________ N.E.L. OBSERVER ______________

PUMP TEMPERATURE °C	SUCTION MANOMETER TEMPERATURE °C	MANOMETER Nº 1 ["Hg]	MANOMETER Nº 2 ["Hg]	MANOMETER Nº 3 ["Hg]

	READING ["Hg]	READING ["Hg]	READING ["Hg]

	ZERO ["Hg]	ZERO ["Hg]	ZERO ["Hg]

CALIBRATION REF.		

SUCTION PRESSURE GAUGE	lb/in²

MAX. TAP DIFFERENTIAL	mm Hg.

M 2	

N.E.L ______________

D.M.J.M. ______________

______________ PUMP MANUFACTURER ______________

FIG 24 SPECIMEN DATA SHEET (SUCTION HEAD)

DATE ________ TEST RUN Nº ________ N.E.L. OBSERVER ________

BAROMETRIC PRESSURE HEAD ("Hg)

AIR TEMPERATURE (°F)

________ PUMP

N.E.L. ________

D.M.J.M. ________

MANUFACTURER ________

FIG 25 SPECIMEN DATA SHEET (BAROMETRIC PRESSURE AND TEMPERATURE)

SINGLE LINE SUCTION MANOMETERS

Date: Pump tested:

	Manometer	Time of day	Temperature ($^{\circ}$C)	Zero (inHg)	K_a*
Before test	No 1				
	No 2				
	No 3				
After test	No 1				
	No 2				
	No 3				

*K_a values calculated from calibration carried out on Reference No

NEL observer:

Other observers:

FIG. 26. SPECIMEN CALIBRATION SHEET FOR SUCTION MANOMETERS

FIG. 27. NEL SINGLE LIMB MERCURY/WATER MANOMETERS

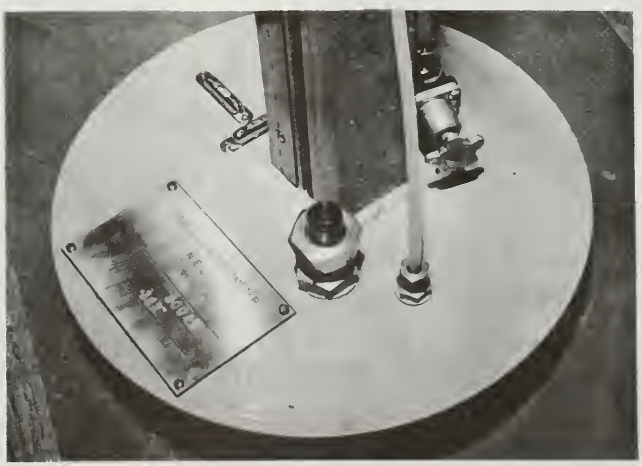


FIG. 28. BASE OF SINGLE LIMB MANOMETERS

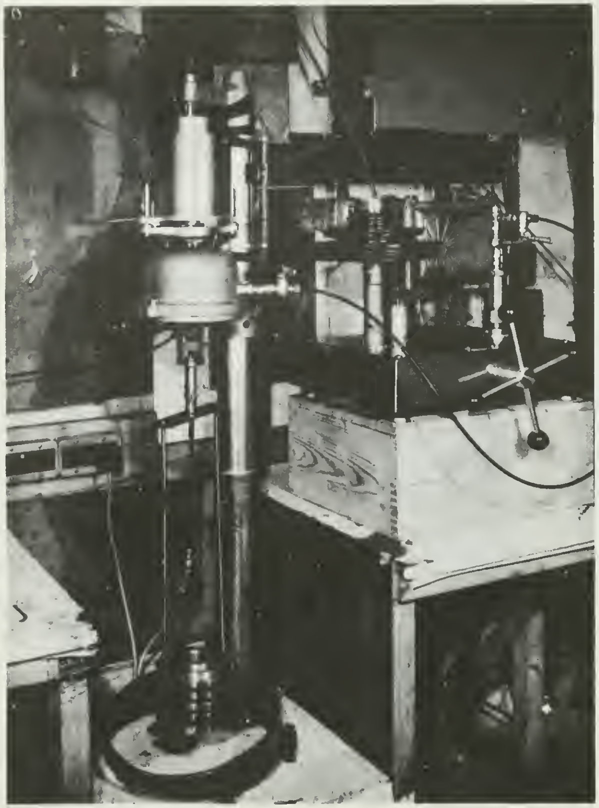


FIG. 29. PISTON GAUGE MANOMETER

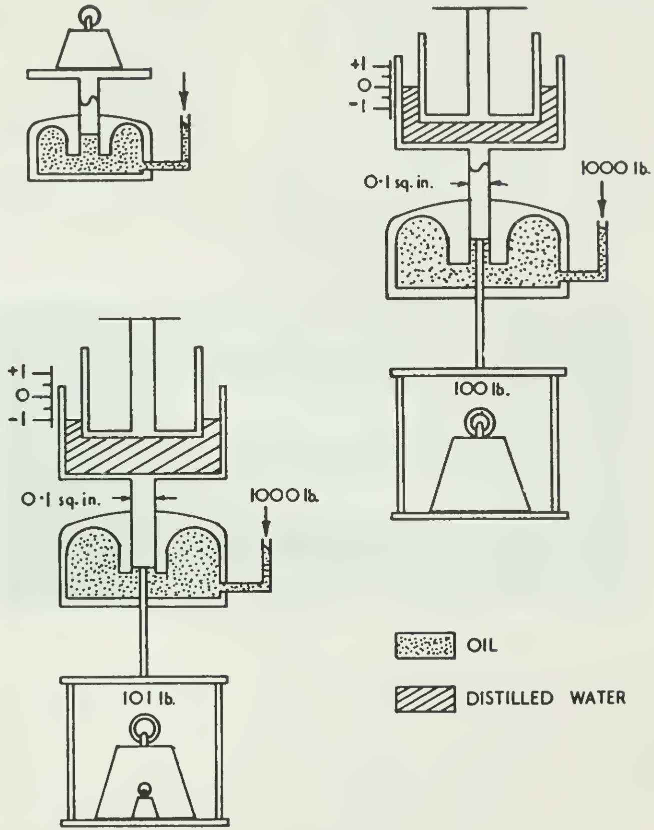


FIG 30 PRINCIPLE OF PISTON GAUGE MANOMETER

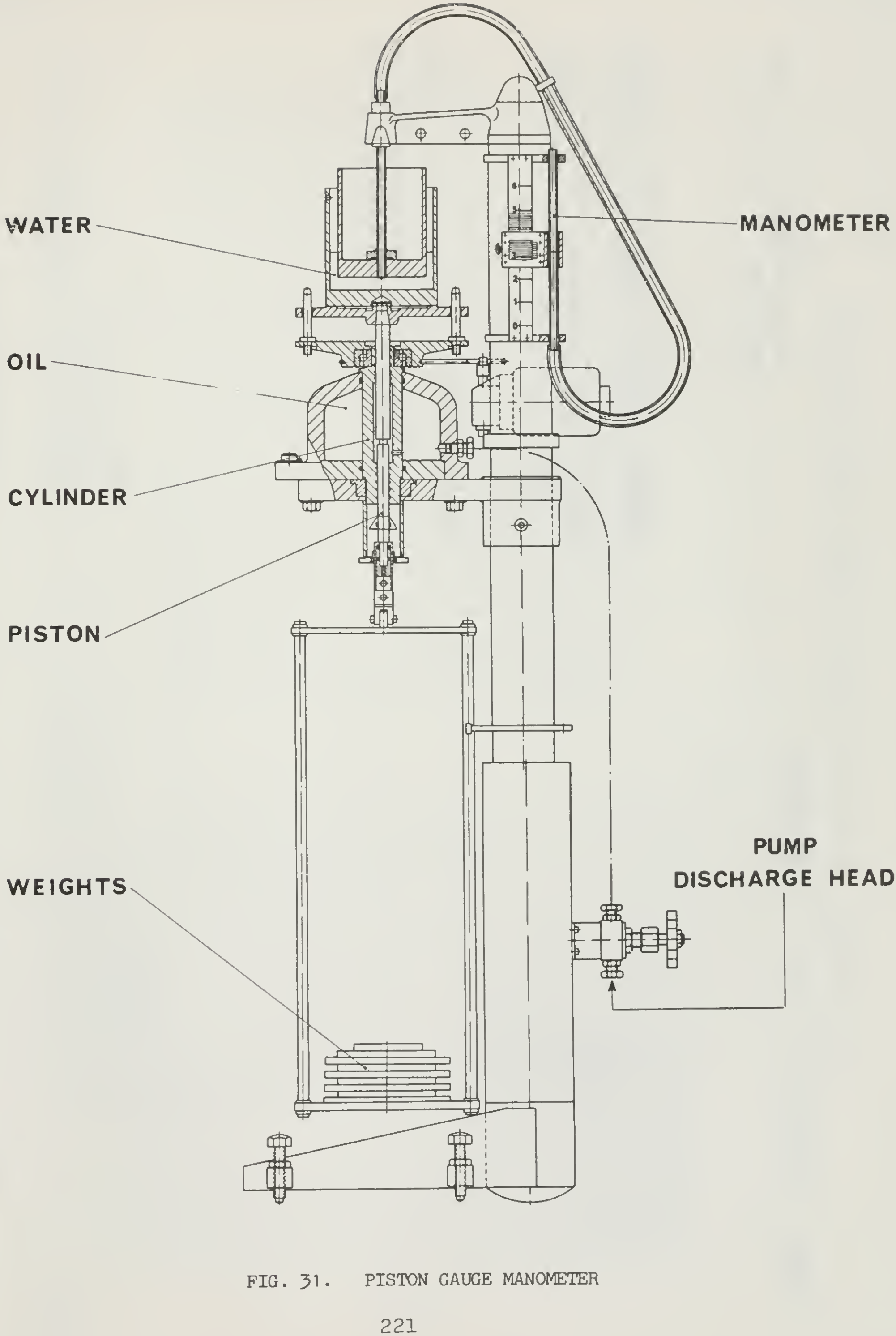


FIG. 31. PISTON GAUGE MANOMETER

DATE ____________ TEST RUN Nº ____________ N.E.L. OBSERVER ____________

W_2 [lb]

DISCHARGE PRESSURE GAUGE	lb/in^2
DISTILLED WATER TEMPERATURE	°C
h_y =	in
MAX. TAP DIFFERENTIAL	m.m.Hg.
CALIBRATION REF.	

PUMP ____________

N.E.L. ____________

D.M.J.M. ____________

MANUFACTURER ____________

FIG 32 SPECIMEN DATA SHEET (DISCHARGE HEAD)

PISTON GAUGE MANOMETER — CALIBRATION SHEET

DATE ______________ | N.E.L. OBSERVER ______________

POINT	P PRESSURE APPLIED TO DEAD WT. TESTER	W WEIGHT REQUIRED TO BALANCE P.G.M.	KW + C	% DEVIATION = P-(KW+C) /P %
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

K =	C =

______________ PUMP

CALIBRATION REF P.G.M. / / /67

N.E.L. ______________

D.M.J.M. ______________

MANUFACTURER ______________

FIG 33 SPECIMEN CALIBRATION SHEET FOR PISTON GAUGE MANOMETER

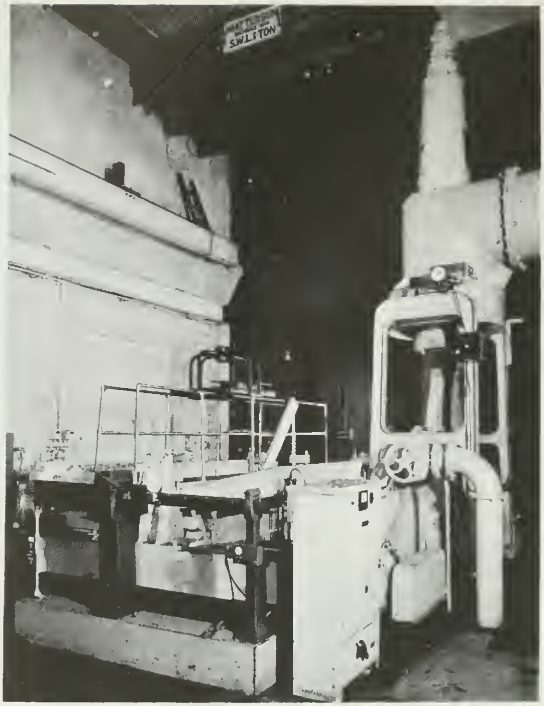


FIG. 34a. GENERAL VIEW OF No 3 CONTROL VALVE DIVERTER AND WEIGH-TANK

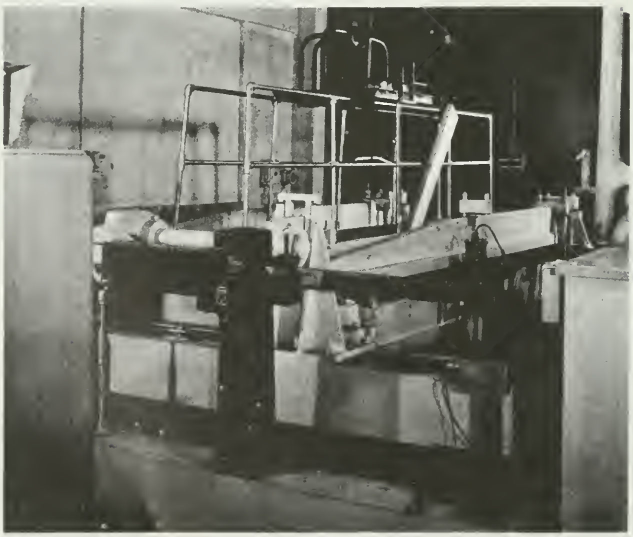


FIG. 34b. WEIGH-TANK AND DIVERTER

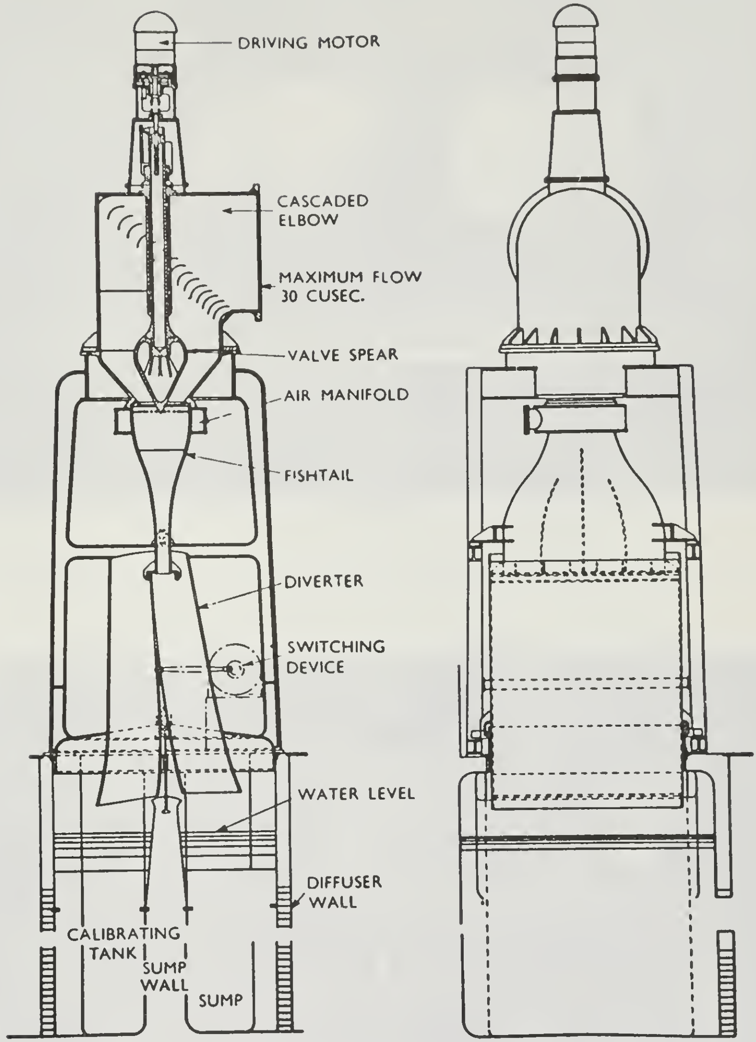


FIG. 35. DIVERTER SYSTEM

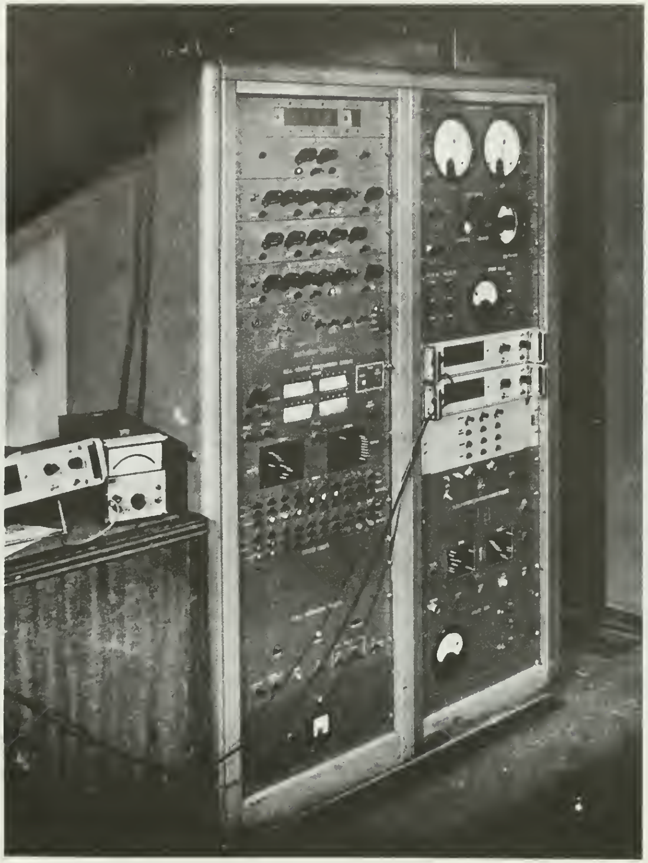


FIG. 36a. WEIGH-TANK CONTROL CONSOLE

FIG. 36b. WEIGH-TANK FLOWMETER AND TEMPERATURE RECORDER

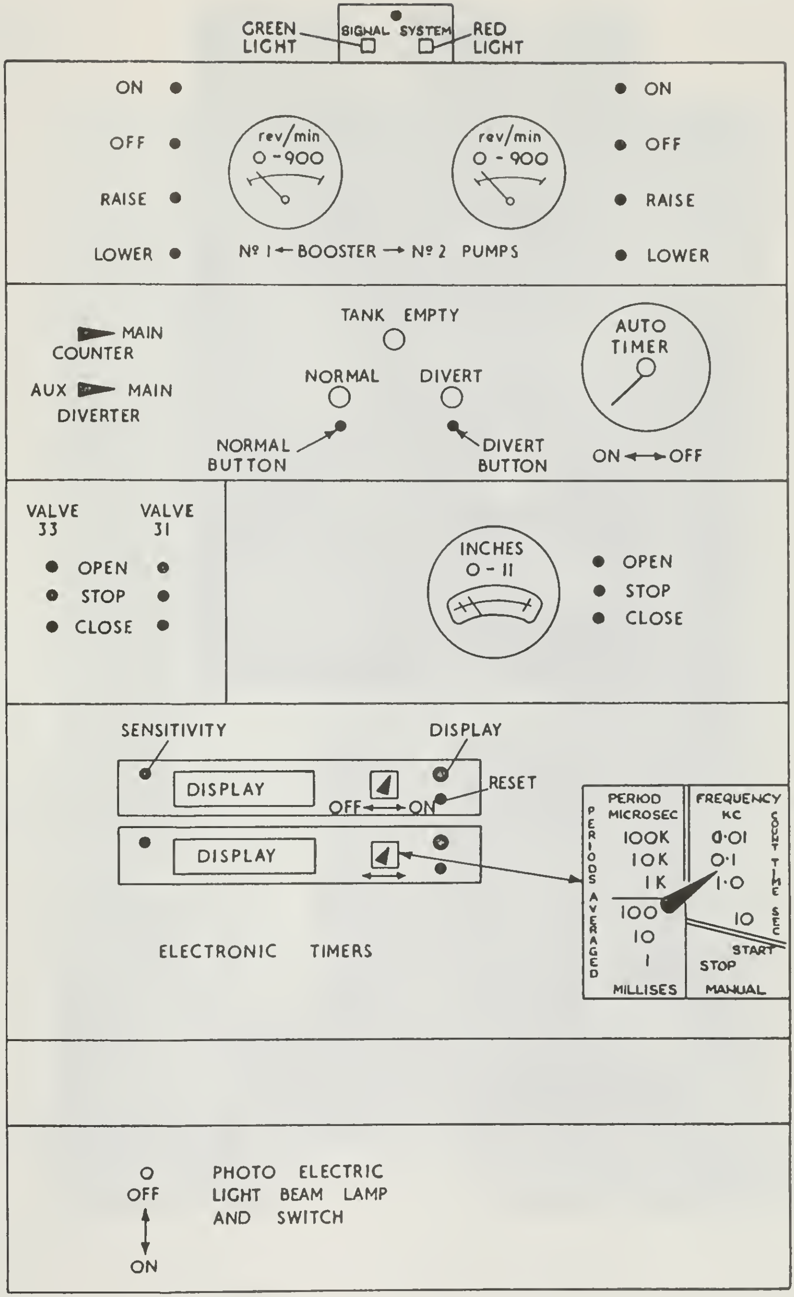


FIG 37 WEIGHTANK CONTROL AND INSTRUMENT CONSOLE

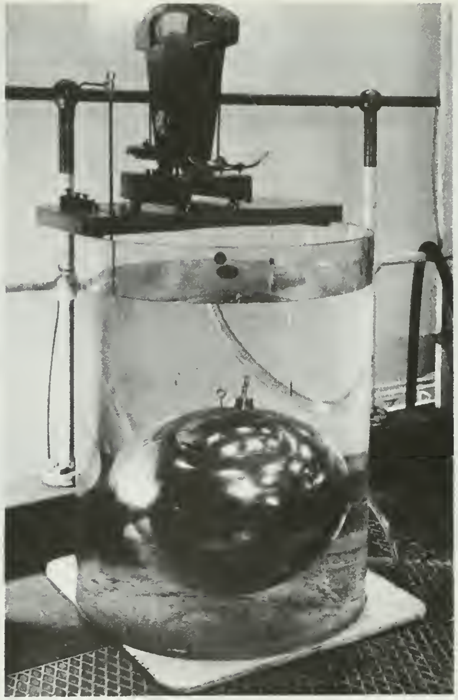


FIG. 38. MEASUREMENT OF SPECIFIC GRAVITY OF WATER

DATE ______ TEST RUN Nº ______ N.E.L OBSERVER ______

WEIGHTANK WEIGHT BEFORE [lb.]	DIVERSION TIME [sec.]	WEIGHTANK WEIGHT AFTER [lb.]

TIME OF DAY	hrs.
E.M. FLOWMETER	cusec.

SPECIFIC GRAVITY

N.E.L. ______

D.M.I.M. ______

______ PUMP

MANUFACTURER ______

FIG 39 SPECIMEN DATA SHEET (FLOWRATE)

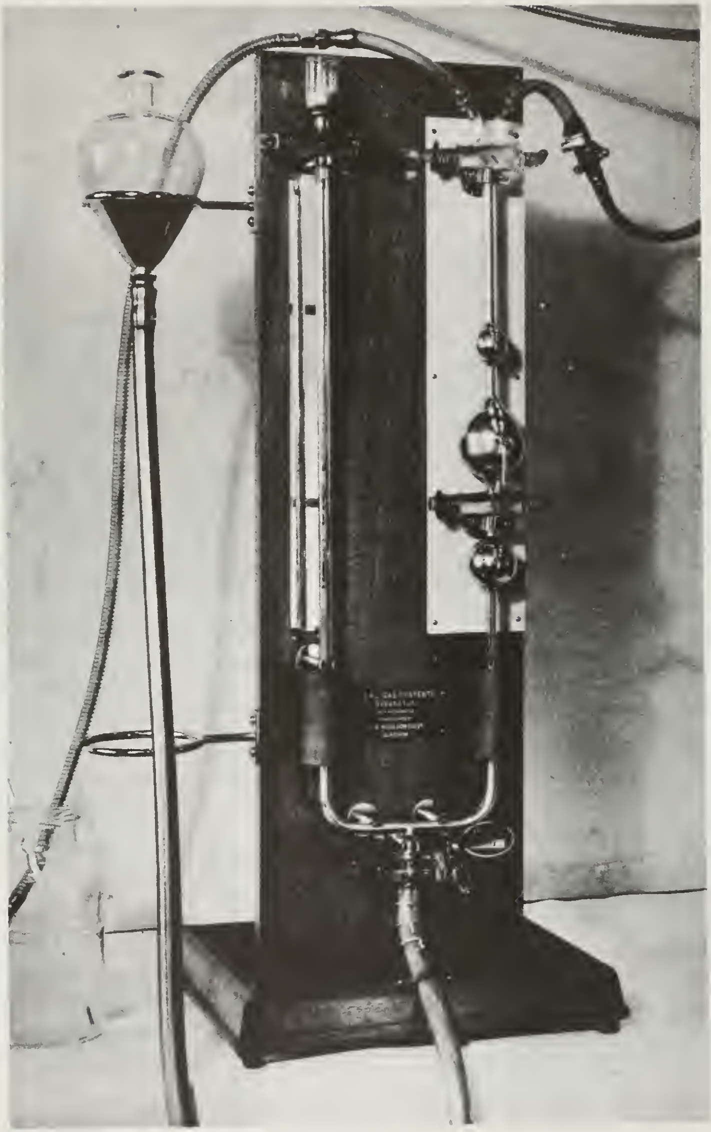


FIG. 40. AIR CONTENT MEASURING APPARATUS

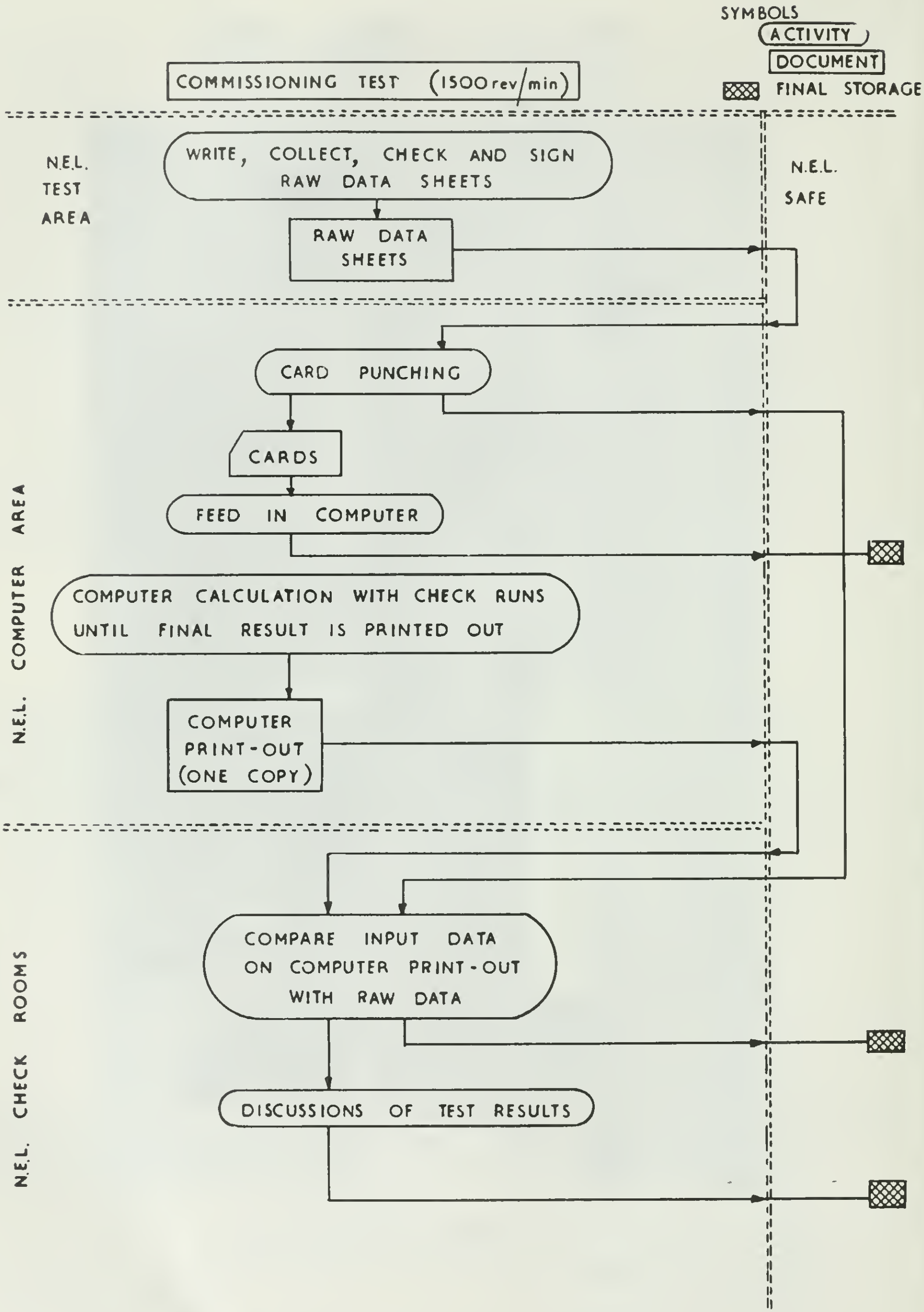


FIG 41 DATA FLOW CHART FOR COMMISSIONING TEST 1500 REV/MIN

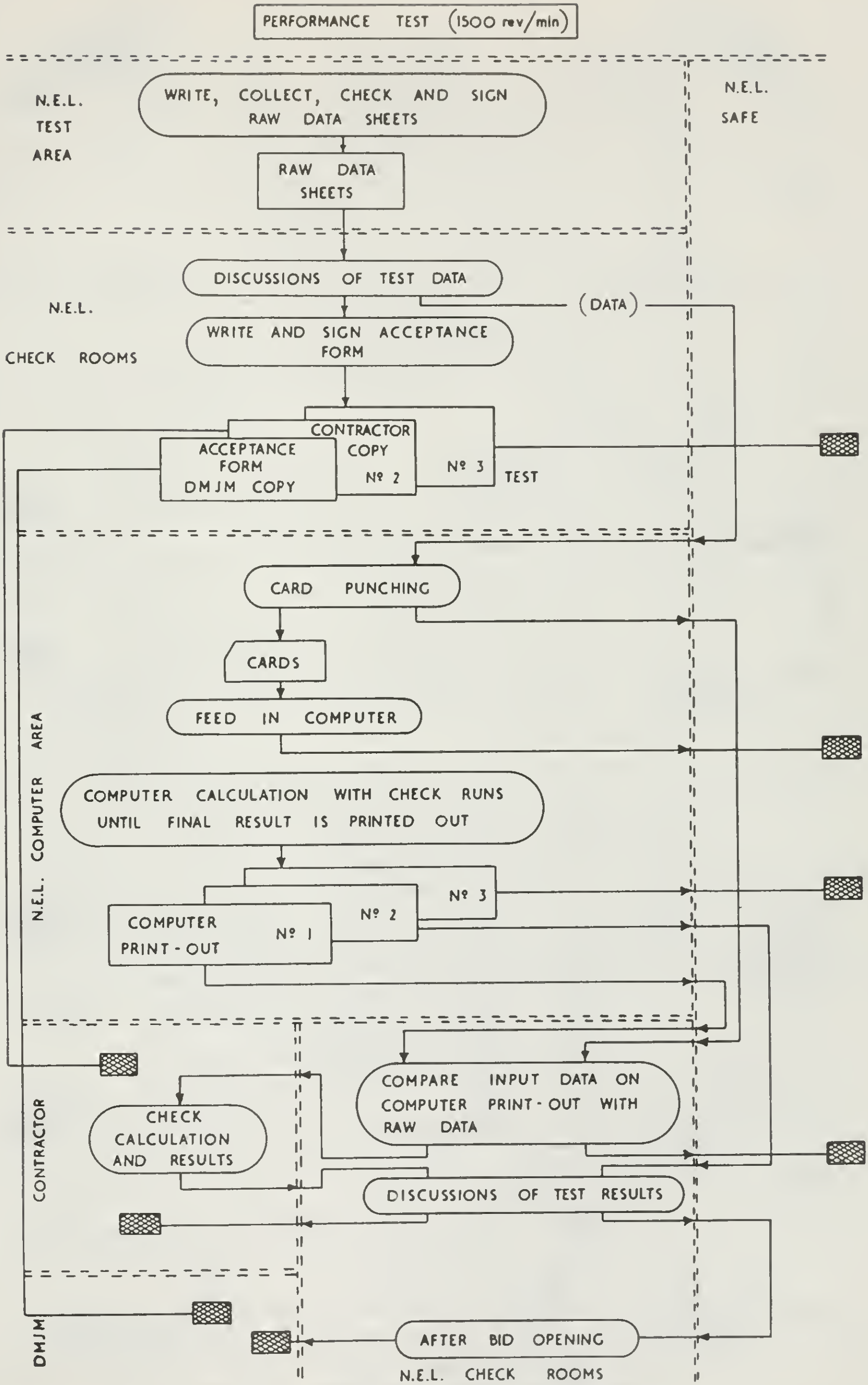
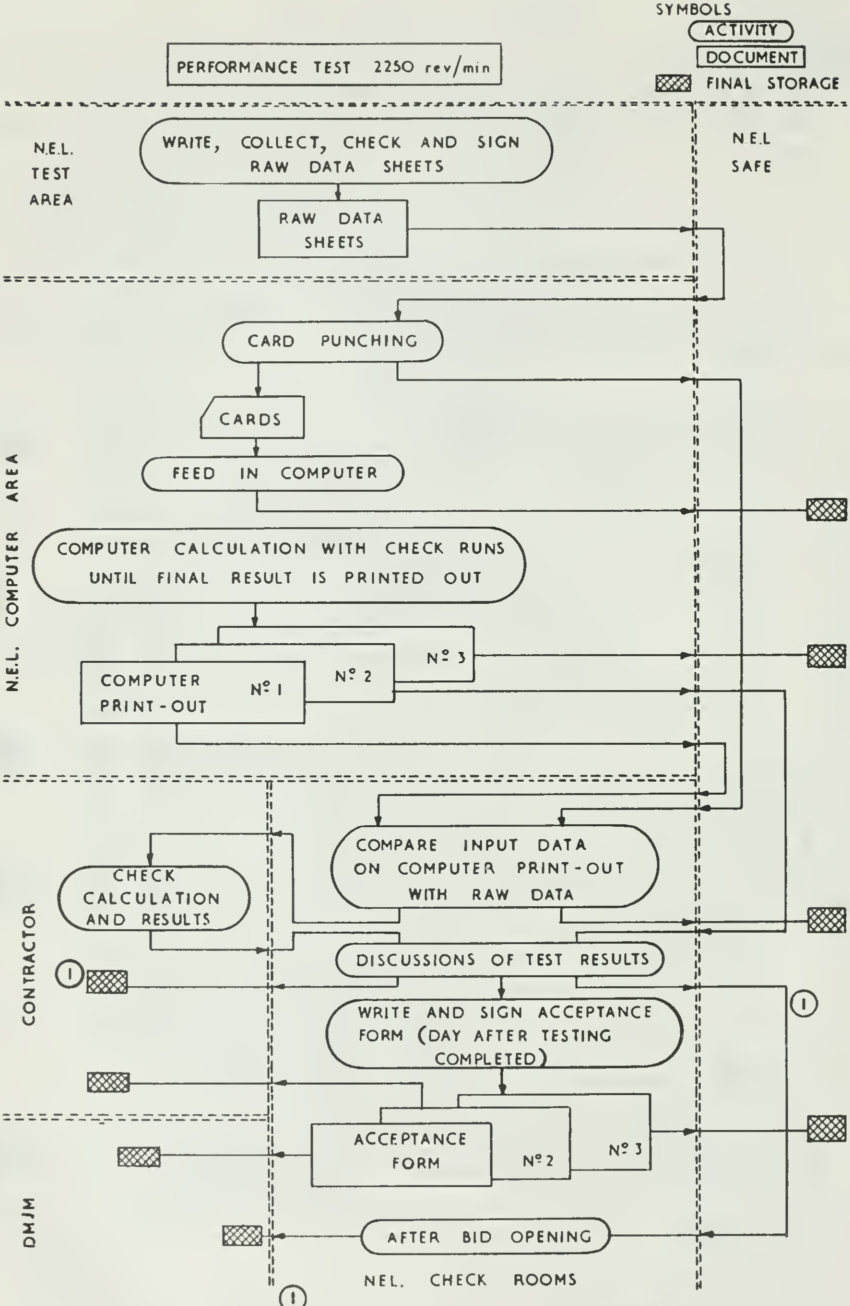


FIG 42(a) DATA FLOW CHART FOR PERFORMANCE TEST AT 1500 REV/MIN



NOTE :- IN THE EVENT 2750 rev/min TESTS ARE INSUFFICIENT FOR ALL MODELS, COMPUTER PRINT-OUTS WILL BE RETURNED TO POINT (2) ON FIG 43 (2750 rev/min TESTS) AND WILL BE TREATED AS OFFICIAL AND FOLLOW THE OFFICIAL DATA FLOW CHART FROM POINT (2)

FIG 42(b) DATA FLOW CHART FOR 2250 REV/MIN PERFORMANCE TESTS

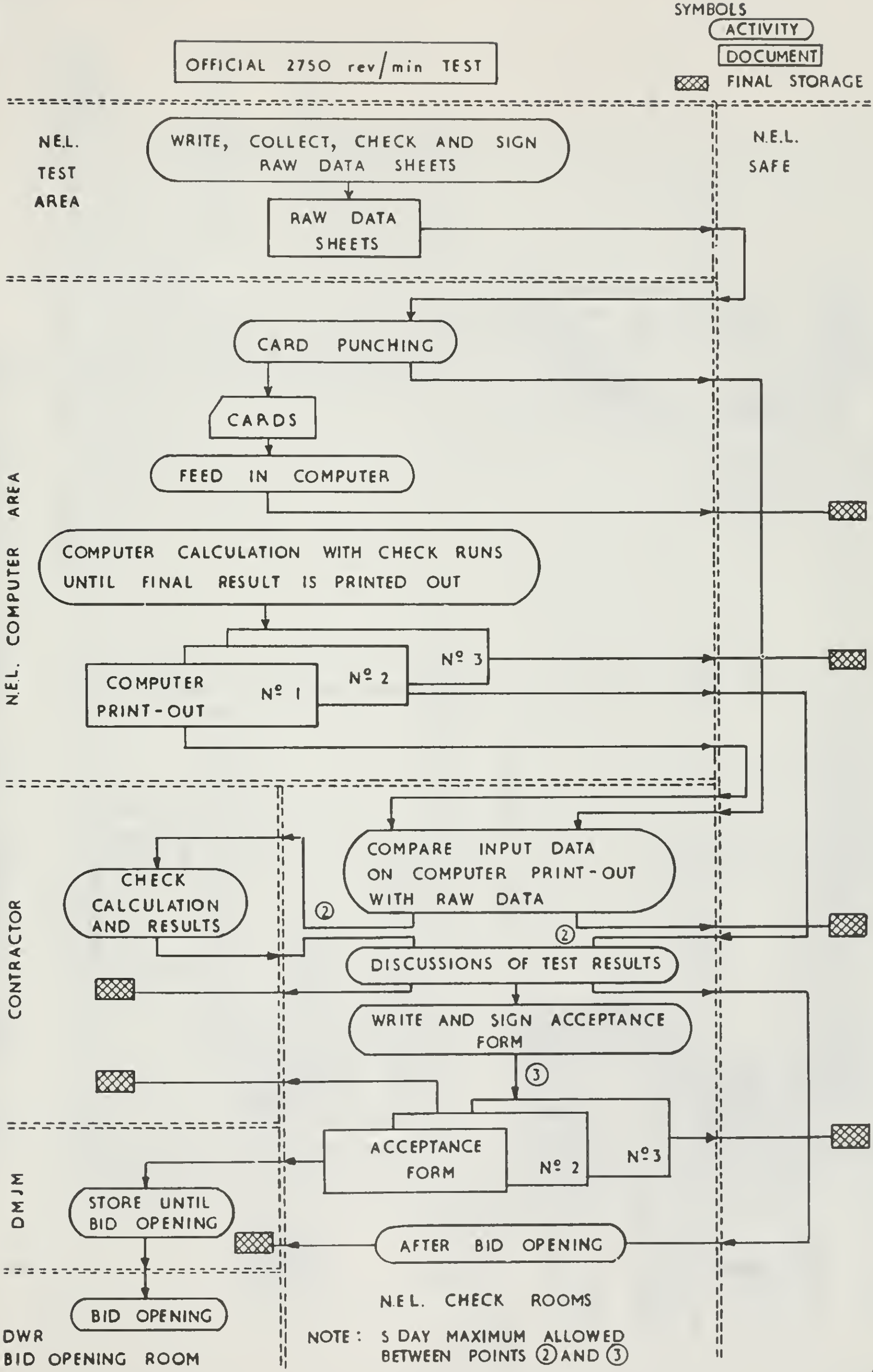
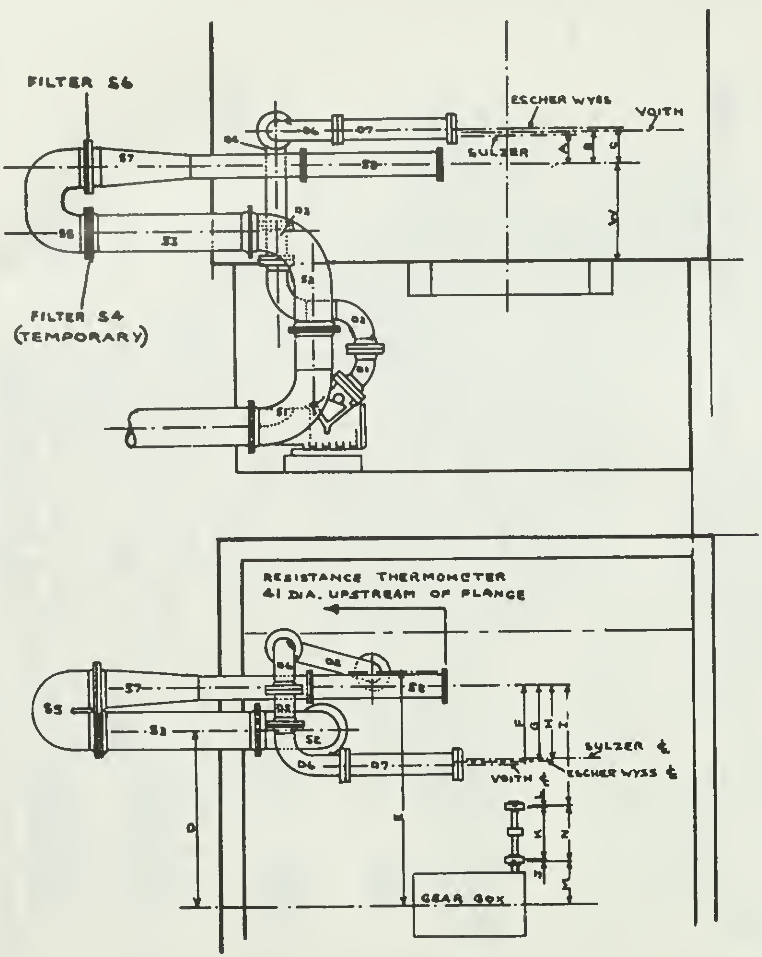
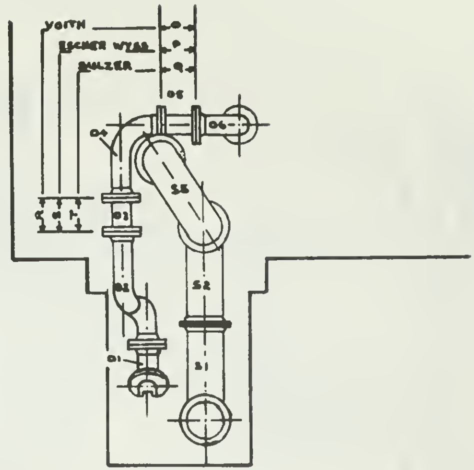


FIG 43 DATA FLOW CHART FOR OFFICIAL TESTS AT 2750 REV/MIN



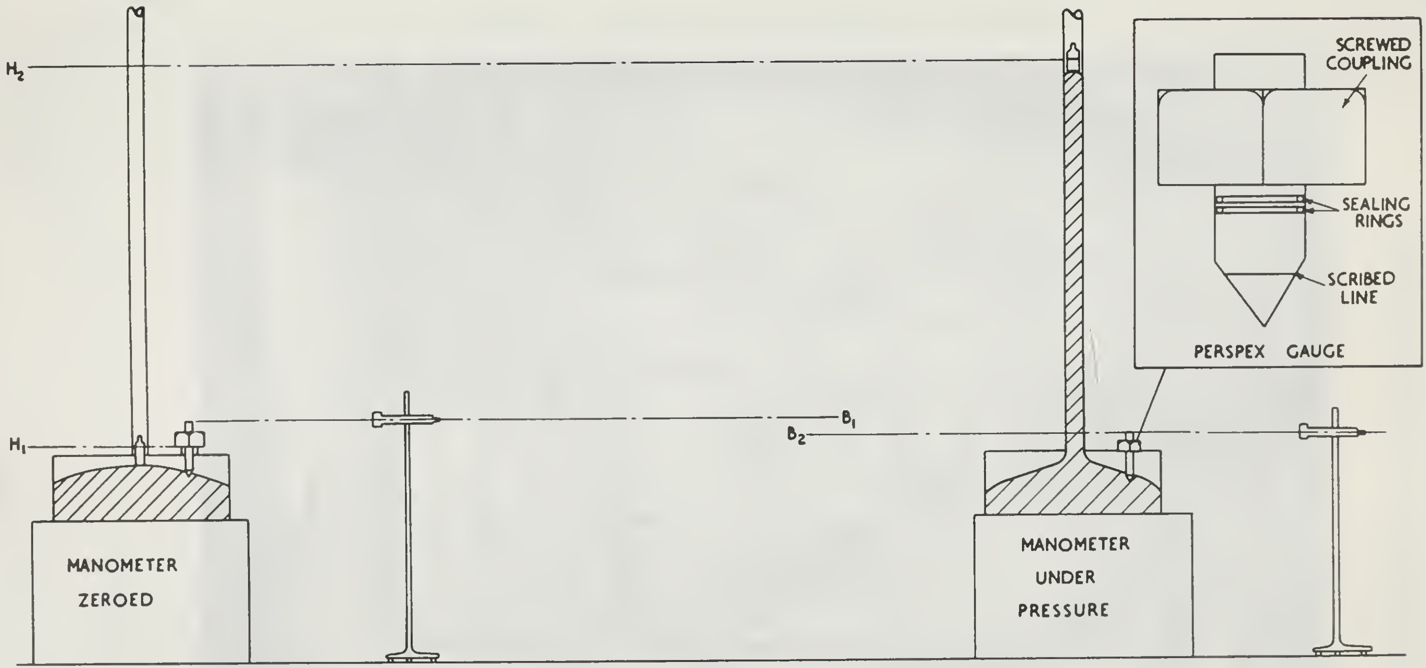


	FT	IN
A	1	4 1/32
B	1	5 11/64
C	1	6 3/8
D	7	10 7/8
E	10	5 1/8
F	3	0 11/32
G	3	3 1/4
H	3	2 25/32
I	5	2 1/4
J	0	1
K	2	4 1/2

	FT	IN
L	0	0 3/4
M	1	11
N	2	6 1/4
O	0	8 1/4
P	0	11 1/8
Q	0	10 21/32
R	1	3
S	1	1 5/64
T	1	0 21/32
W	4	2 1/2

REDUCED FROM DRAWING No Y2/03899

FIG 44 PIPING ARRANGEMENT FOR TEHACHAPI EVALUATION TESTS



$$\text{RATIO} = \frac{\text{HEIGHT} \quad H_2 - H_1}{\text{HEIGHT} \quad B_1 - B_2} = R$$

$$K_{area} = 1 + \frac{1}{R}$$

$$= 1 + \frac{B_1 - B_2}{H_2 - H_1}$$

AVERAGE VALUE OF K_{area} FOR EACH MANOMETER

$$\text{MEAN } R = \frac{\Sigma R}{n} = \bar{R}$$

$$K_{area} \text{ (AVERAGE)} = 1 + \frac{1}{\bar{R}}$$

FIG 45 DETERMINATION OF AREA RATIOS OF SINGLE LIMB MANOMETERS

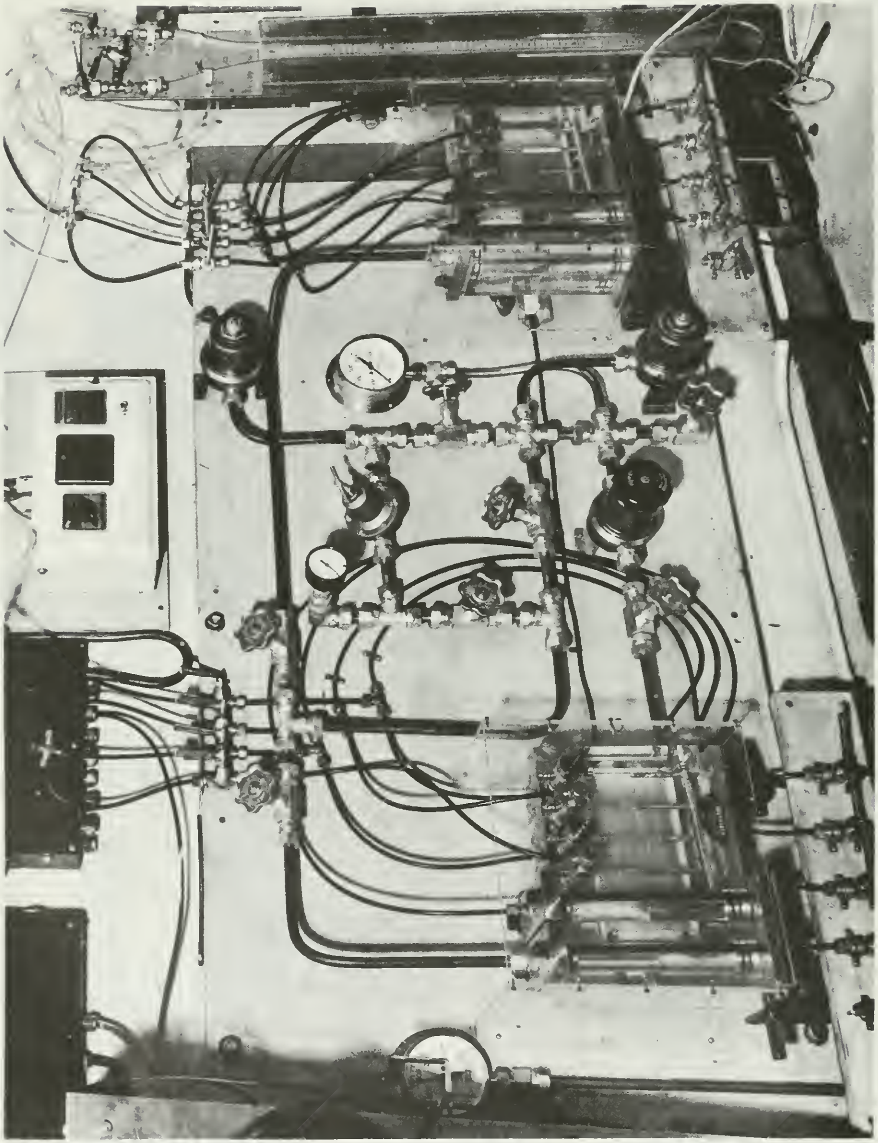


FIG. 46. PRESSURE TAPPING DIFFERENTIAL MANOMETERS

COMMERCIAL-IN-CONFIDENCE

T. 2.

MINISTRY OF TECHNOLOGY

NATIONAL ENGINEERING LABORATORY

REPORT

on

TEHACHAPI BIDDER'S MODEL TESTS

Part 1. Test Programme and Summary of Results

for

Daniel, Mann, Johnson and Mendenhall
Consultants to the Department for Water Resources
State of California

(MADE UNDER THE CONDITIONS STATED OVERLEAF)

Reference: RY/14/6631

EAST KILBRIDE,
GLASGOW.

Date: 12th October, 1967.

NOTES.

Tests or Investigations are carried out only at the discretion of the Director of National Engineering Laboratory, acting on behalf of the Ministry of Technology.

Investigatory Tests into the properties of materials and the Testing and Verification of Instruments (and in connexion therewith of their component parts) can be undertaken by the Laboratory. Ordinary Contractual Testing of materials, i.e., testing of materials for the purpose of ascertaining whether their quality and behaviour are in accordance with the requirements of contracts, is not undertaken except as described below:-

(1) When required by a Government Department;

(2) When the tests cannot be carried out adequately in any existing private establishment;

(3) When the tests arise as reference tests, agreed as such between parties to a contract or referred to the Laboratory by a Court of Law or Arbitration.

In general, reports are not intended for use in legal or arbitration proceedings, especially those which might involve the attendance of members of the staff of the Laboratory.

In regard to the reservation of the right of publication (*see* Condition 8) it is not the intention of the Laboratory to reveal specific information which may properly be confidential to the applicant, but to publish when necessary generalised results of value to industry as a whole.

CONDITIONS.

Tests and Investigations are subject to the following conditions:-

1. The Ministry reserves the right to decline any proposal for the undertaking of a test or special investigation.

2. All materials, equipment, etc., to be tested or investigated shall be delivered and collected, at the cost of the applicant, and in accordance with the requirements of, the Ministry.

3. No liability shall be incurred by and no claim shall be made against the Crown or any servant or agent of the Crown or any person employed at the Research Station in respect of any loss or damage to any of such materials, equipment, etc., occurring at the Research Station or in the course of transit to or from the Research Station, and whether or not resulting from any act, neglect or default on the part of any servant or agent of the Crown or any person employed at the Research Station.

4. The Ministry does not accept any responsibility for loss or damage arising from the use of information contained in any of its reports or in any communication about its tests or investigations.

5. The estimated fee for the cost of the work, will be quoted in advance, and this estimate will not be exceeded without reference to the applicant.

6. Fees are prepayable, and should accompany this form.

7. Tests will not be made on proprietary or patented materials unless all particulars, including the composition and method of manufacture, are disclosed and can be indicated in the report.

8. If the test or investigation is required of a material or product which has failed in use or in connexion with any dispute, whether or not the dispute is the subject of contemplated or actual arbitration or legal proceedings, the circumstances must be fully disclosed by the applicant. In such circumstances the Ministry cannot undertake to place its services at the disposal of any one party. The investigation, if undertaken, and the subsequent report would have to be open to all parties who would be expected to provide either at their own initiative or on request any relevant information, and to agree to accept the Ministry's findings.

9. Availability of Reports.

(a) Reports involving third parties, such for example as those furnished in the circumstances indicated in 8 above, may not be published in whole or in part or in abridged form by any of the applicants. The Ministry, however. reserves the right in its absolute discretion to publish such of the results of any such investigation as it deems to be of general interest.

(b) Reports not involving third parties may be freely published by the applicant, except in, or in connexion with any Company prospectus or similar publication, provided that such publication is verbatim and in full. If the Ministry notifies the applicant that it is seeking patent protection as provided for in condition 10, the applicant will be required to undertake not to publish any report without the prior consent of the Ministry. No extract from or abridgment of any report may be published without the prior consent of the Ministry, nor may any report be published (in whole or in part) in, or in connexion with, any Company prospectus or similar publication without such prior consent, which if given, may, in both cases be subject to conditions. The Ministry reserves the right to publish the results either in whole or in part together with any comments and additional matter which it thinks desirable, but will not in general expect to exercise that right except as regards results deemed to be of general interest. The Ministry will in any case consult the applicant beforehand.

10. If during the progress of the tests or special investigations discoveries are made originating with the officers of the Ministry concerned and relating to the subject-matter of the tests or special investigations, the Ministry may, after consulting the applicant, but in its absolute discretion, secure the ownership by patent, registered design or copyright in Great Britain and Northern Ireland or elsewhere, and the applicant shall be entitled to use the discoveries so secured by patent, etc., as follows:-

(1) In Great Britain and Northern Ireland - under a free non-exclusive, non-transferable licence.

(2) Elsewhere - under a licence or otherwise, but in all cases on such terms as may be determined by the Ministry in its absolute discretion.

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NATIONAL ENGINEERING LABORATORY

Fluid Mechanics Division - Fluids Group

REPORT

on

TEHACHAPI BIDDER'S MODEL TESTS

Part 1. Test Programme and Summary of Results

for

Daniel, Mann, Johnson and Mendenhall
Consultants to the Department for Water Resources,
State of California

SUMMARY

This Part deals with general aspects of the Tehachapi bidders model tests. Lists are given of the observers attending and graphs and photographs summarize the results obtained on each model pump. The list of references gives details of the various reports issued by NEL in the course of the tests.

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Antony Spencer
Superintendent
For F. D PENNY
Director

NATIONAL ENGINEERING LABORATORY

(ii)

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1. INTRODUCTION

The three bidders model tests for the Tehachapi pumping plant were carried out during the period from May-August 1967. The general programme of the tests had been laid down in the consultants specification(1) and the detailed procedures recommended by NEL and adopted after the Observers Briefing meeting 13th/21st April, 1967, were presented in the Laboratory Procedure Report(2)(3). The Laboratory Procedure Report, Fluids Memo No 272, and Appendix 6 to this Report, Fluids Memo No 275, were issued before the first model pump arrived and adhered to throughout the test programme. Also at this time a Fluids Memo(4) was issued describing the deadweight calibration of the weighbridge in April.

Since it was important that the principle laid down in the Procedure Report, that observers should be kept fully informed, should be carried out, a series of short test reports, TRs 1-21, have been issued between May and September(5-25). These reports have included general notes, calibrations of instruments and examinations of the measuring pipe sections. Minor typographical errors and amendments to the Laboratory Procedure Report were listed in TRs 4, 7 and 8(8, 11, 12), and a complete example of the calculations for a test point was given in TR 5(9). The computer program was extended to cover the print-out if the maximum efficiency were to lie outside the 305-325 cusec range(19). This program was used to determine the efficiency within the specified range for the AC/Sulzer tests.

The detailed description of the tests on each model pump is given in separate Parts of this Report. Part 2 gives details of the first pump tested, that provided by the Baldwin-Lima-Hamilton/Voith consortium(26), Part 3 deals with that of the Allis Chalmers/Sulzer consortium(27), and Part 4 with that of the Newport News/Escher Wyss consortium(28). Reproductions of all the computer print-out sheets accepted as covering the official tests are included in these separate parts.

2. OBSERVERS AND VISITORS

The NEL staff involved in the tests are listed in TR 19(23). The consultants' and manufacturers' observers who came to NEL during the tests are listed below together with the periods covered.

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State of California

D.M.J.M., Consultants representatives

Mr. R. D. Bowerman*	15.6.67 and 16.6.67
	20.6.67 - 23.6.67
Mr. R. Burge*	17.4.67 - 20.7.67
	14.8.67 - 18.8.67
Mr. H. Gartmann*	17.7.67 - 20.7.67

Motor Columbus, Consultants representatives

Mr. O. Hartman*	19.5.67 - 2.6.67
Mr. A. Engel	23.5.67 - 2.6.67
	13.6.67 - 29.6.67
	7.7.67 - 20.7.67
	15.8.67 - 17.8.67

Baldwin Lima Hamilton

Mr. B. L. Lane*	20.5.67 - 2.6.67
Mr. R. S. Quick*	20.5.67 - 2.6.67

Voith (Heidenheim)

Mr. F. Wolfram*	19.5.67 - 2.6.67
Mr. H. Offenhauser	16.5.67 - 2.6.67
Mr. W. Link	11.5.67 - 2.6.67

Allis Chalmers

Mr. D. Rehrer*	15.6.67 - 28.6.67

Sulzer Bros.

Dr. H. Thomae*	14.6.67 - 28.6.67
Mr. E. Sigrist	8.6.67 - 28.6.67
Mr. J. Bachler	8.6.67 - 22.6.67
Mr. D. Schwarz	22.6.67 - 28.6.67

Newport News Shipbuilding & Dry Dock Co.

Mr. R. M. Donaldson*	7.7.67 - 18.7.67
	14.8.67 - 17.8.67

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Escher Wyss

Mr. A. Lecher	13.7.67	-	18.7.67
	14.8.67	-	17.8.67
Mr. E. Egg*	7.7.67	-	13.7.67
	10.8.67	-	18.8.67
Mr. H. Amrein	4.7.67	-	13.7.67
	10.8.67	-	13.8.67
Mr. H. Stucki	4.7.67	-	13.7.67
	10.8.67	-	13.8.67.

Those marked by an asterisk in the above list were present at the Observers Briefing meeting.

Mr. A. M. Whitsett, representing the Metropolitan Water District of Southern California, was present throughout the test period from 20th May to 28th August. He was present each evening that tests took place, arriving in time to see the final checks before starting up the motor and staying until the NEL team were ready to start the first test measurements of the night. Fig. 1(a) reproduces the statement which Mr. Whitsett signed on arrival and departure.

Apart from Mr. Whitsett, the only other visitor who was permitted to go into the Pump Test House during the test period was Mr. S. Svenson of D.M.J.M. who visited the Laboratory on 19th July. Fig. 1(b) reproduces his signed statement.

3. CALIBRATIONS AND CHECKS

The programme was not carried out without incident the emergency stop button being pressed on occasions during each model test, sometimes because of the concern of the manufacturer's representative at the mechanical performance of his model and at others because of a suspected fault in the driving equipment. Shut-downs followed immediately and no damage to the pumps was caused.

The tests were very successful from NEL's view, no significant hold ups being caused by NEL equipment and the analysis of the results showing that their consistency for all three models was even better than had been predicted. A few punching errors were spotted in the thousands of cards punched from the raw data and the computer print-out sheets had to be re-run on occasions because of minor machine faults. Minor mistakes in the computer program were discovered at the

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beginning of the first model tests and these were quickly put right (TR 4[6]) so that correct results were obtained within a day. The print-out sheets were, for every night's test, available for the following morning's meeting.

Speed measurements gave no troubles nor did suction and delivery head measurements. A few test points were invalidated by the Chief of Tests immediately after they were taken for various reasons such as speed variation, insufficient weight diversion, torque read out brush signal etc. The calibrations of the suction and piston gauge manometers, the torque tubes and the weighbridge and diverter showed that these all remained constant throughout the tests. The checks before each series of tests of the diameters and appearance of the suction and delivery pipe measuring sections showed that these also remained unchanged over the whole period.

It had been agreed that the official tests should be carried out in the temperature range 25-30°C. This range was adhered to for the 2250 and 2750 rev/min tests. It was realised at the beginning of the first model tests that a very long time would be wasted if the temperature of the water had to be warmed up to 25°C for the 1500 rev/min tests as the horse-power input was so small. For these tests, therefore, for each model the water temperature was below 25°C.

4. RESULTS

The raw data and calculated test results for each model pump are given in Parts 2, 3 and 4. These results were plotted during the tests on graphs and the inked-in versions of these graphs are reproduced in Figs 2-10. Photographs of the model pumps on the test stand and reproductions of the cavitation sketches and photographs follow in Figs 11 onwards.

Figs 14-17, 31-34, and 57-60 are reduced scale versions of the graphs quoted above and these are also included in Parts 2, 3 and 4 respectively. Additional figs are included in these Parts where they relate specifically to the pump dealt with. These figs include the Acceptance Forms signed at each stage of the tests.

Each model pump is dealt with separately as follows:

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BLH/Voith model pump

Fig. 11 model pump on test stand
12 observation windows on model pump
14-17 graphs showing performance at 1500, 2250 and 2750 rev/min
23-27 sketches of observation of impeller blades at various suction specific speeds
18-22 photographs of impeller blades at various suction specific speeds

AC/Sulzer model pump

Fig. 28 model pump on test stand
29 observation windows on model pump
31-34 graphs showing performance at 1500, 2250 and 2750 rev/min
40-53 sketches of observation of impeller blades at various suction specific speeds
35-39 photographs of impeller blades at various suction specific speeds

Newport News/Escher Wyss model pump

Fig. 54 model pump on test stand
55 observation windows on model pump
57-60 graphs showing performance at 1500, 2250 and 2750 rev/min
67-75 sketches of observation of impeller blades at various suction specific speeds
61-66 photographs of impeller blades at various suction specific speeds.

As noted in Part 3, discussion took place to clarify the interpretation of which test points should be used for the curve-fitting to obtain the maximum efficiency point. The precedent set up in the first series of tests, those on the BLH/Voith pump, was generally adhered to although the number of test points used for each curve-fit, of necessity, varied, as well as the sequence. The questions at issue were (a) whether the first few points, run to check repeatability at 100 per cent, should be included since they would give extra weight to the curve-fit at this point; (b) whether the test runs when cavitation observations or photographs were taken should be included.

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For the BLH/Voith model the first four repeatability tests at 2250 rev/min were not made and so these were not included in the AC/Sulzer and NN/Escher Wyss curve-fits. On the other hand, the cavitation test runs at 6000 and 7000 suction specific speed were included in the BLH/Voith curve-fit and so these were also included in the AC/Sulzer curve-fit. In the case of NN/Escher Wyss, the cavitation measurements over a range of suction specific speeds were made as a separate study and the curve-fit was based, therefore, on Test Series 3(a) alone. Since all pump models ran at 2750 rev/min the curve-fits obtained at 2250 rev/min were not required for bid evaluation.

At the time of the AC/Sulzer tests it was decided that the course to be followed for the 2750 rev/min curve-fitting should be that only the last point of the repeatability series should be included (thus the first four test runs at 100 per cent were to be discarded) and that cavitation test runs should be counted as being a separate test and therefore should not be included. This procedure was adopted, therefore, for the AC/Sulzer and NN/Escher Wyss curve-fitting. In the BLH/Voith tests, however, the five repeatability test points had all been included and also the 7000 suction specific speed cavitation test runs. The cavitation runs at 6000 suction specific speed had not been included nor of course those at 10,000 suction specific speed.

To check whether this variation in handling the curve-fitting could have had any effect on the maximum efficiency the BLH/Voith curve-fit has been re-run leaving out test points 62, 64, 65, 66 (repeatability points) and 100, 101, 102, 106 (cavitation points). The shift in maximum efficiency was from 89.61 to 89.63 per cent, a shift of only 0.02 per cent. This shift has no effect on the scaled-up value of 92.2 per cent used for the bid evaluation.

5. CONCLUSION

The tests on the three model pumps were carried out satisfactorily according to the Laboratory Procedure Report and Figs 30-32, 59-61, and 86-88 are reproductions of the signed acceptance forms. The model best efficiency points at the 2750 rev/min test speed within the range equivalent to the prototype flow range of 305-325 cusecs were

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BLH/Voith	89.61 per cent
AC/Sulzer	89.86 per cent
NN/Escher Wyss	88.44 per cent.

These values were stepped up according to the model test specification(1) using the D'/D ratios selected by the manufacturers and the formula given in ref. (1). As a result, the efficiency values to be used in the bid evaluation were

<u>BLH/Voith tender</u>

D'/D ratio = 4.75 per cent
Stepped-up efficiency = 92.2 per cent

<u>AC/Sulzer tender</u>

D'/D ratio = 4.88 per cent
Stepped-up efficiency = 92.4 per cent

<u>NN/Escher Wyss tender</u>

D'/D ratio = 4.73 per cent
Stepped-up efficiency = 91.3 per cent.

ACKNOWLEDGEMENTS

A large number of people participated in the preparation of the test procedures, in carrying out the tests and in their observation. Some of these have already been listed but NEL acknowledges especially the help given by those attending the Observers Briefing meeting. In addition, the assistance of the engineers of the Ministry of Public Building and Works and of the South of Scotland Electricity Board is recorded.

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5. Large size graph showing characteristics of Sulzer model pump at 1500 and 2750 rev/min. Full range performance tests.

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REPORT ON TEHACHAPI BIDDER'S MODEL TESTS

Part 1. Test programme and summary of results
for Daniel, Mann, Johnson and Mendenhall
Consultants to the Department of Water Resources,
State of California

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23. Cavitation sketches of blades at 6000 N.S.S. and 2250 rev/min

24. Cavitation sketches of blades at 7000 N.S.S. and 2250 rev/min

25. Cavitation sketches of blades at 5900, 6000 and 6100 N.S.S. and 2750 rev/min

26. Cavitation sketches of blades at 6900, 7000 and 7100 N.S.S. and 2750 rev/min

27. Cavitation sketches of blades at 9900, 10 000 and 10 100 N.S.S. and 2750 rev/min

28. Model pump on test stand

29. Observation windows in model pump

30. Position of clock gauges used to check vibration of model pump when running

31. Test series 2 and 4c characteristics of model at 1500 and 2750 rev/min

32. Test series 3a and 3b characteristics of model at 2250 rev/min

33. Test series 4a characteristics of model at 2750 rev/min

34. Test series 3c, 3d and 4b cavitation characteristics of model at 2250 and 2750 rev/min

35. Cavitation photographs of blades at 6000 N.S.S. and 2250 rev/min

36. Cavitation photographs of blades at 7000 N.S.S. and 2250 rev/min

37. Cavitation photographs of blades at 10 000 N.S.S. and 2750 rev/min

38. Cavitation photographs of blades at 7000 N.S.S. and 2750 rev/min

39. Cavitation photographs of blades at 6000 N.S.S. and 2750 rev/min

40. Cavitation sketches of blades at 7000 N.S.S. and 2250 rev/min

41. Cavitation sketches of blades at 6000 N.S.S. and 2250 rev/min

Reference: RY/14/6631

Date: 12th October, 1967.

NATIONAL ENGINEERING LABORATORY

13

Continuation

of

REPORT ON TEHACHAPI BIDDER'S MODEL TESTS

Part 1. Test programme and summary of results
for Daniel, Mann, Johnson and Mendenhall
Consultants to the Department of Water Resources,
State of California

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42. Cavitation sketches of blades at 5900 N.S.S. and 2750 rev/min
43. Cavitation sketches of blades at 6000 N.S.S. and 2750 rev/min
44. Cavitation sketches of blades at 6100 N.S.S. and 2750 rev/min
45. Cavitation sketches of blades at 6900 N.S.S. and 2750 rev/min
46. Cavitation sketches of blades at 7000 N.S.S. and 2750 rev/min
47. Cavitation sketches of blades at 7100 N.S.S. and 2750 rev/min
48. Cavitation sketches of blades at 9900 N.S.S. and 2750 rev/min
49. Cavitation sketches of blades at 10 000 N.S.S. and 2750 rev/min
50. Cavitation sketches of blades at 10 100 N.S.S. and 2750 rev/min
51. Cavitation sketches of blades at 9900 N.S.S. and 2750 rev/min
52. Cavitation sketches of blades at 10 000 N.S.S. and 2750 rev/min
53. Cavitation sketches of blades at 10 100 N.S.S. and 2750 rev/min
54. Model pump on test stand
55. Observation windows in model pump
56. Position of clock gauges used to check vibration of model pump when running
57. Test series 2. Characteristics of model at 1500 rev/min
58. Test series 3a and 3b. Characteristics of model at 2250 rev/min
59. Test series 4a. Characteristics of model at 2750 rev/min
60. Test series 3c, 3d and 4b. Cavitation characteristics of model at 2250 and 2750 rev/min

Reference RY/14/6631

Date 12th October, 1967.

NATIONAL ENGINEERING LABORATORY

Continuation

of

REPORT ON TEHACHAPI BIDDER'S MODEL TESTS

Part 1. Test programme and summary of results
for Daniel, Mann, Johnson and Mendenhall
Consultants to the Department of Water Resources,
State of California

61. Cavitation photographs of blades at 6000 N.S.S. and 2250 rev/min
62. Cavitation photographs of blades at 7000 N.S.S. and 2250 rev/min
63. Cavitation photographs of blades at maximum boost pressure and 2750 rev/min
64. Cavitation photographs of blades at 6000 N.S.S. and 2750 rev/min
65. Cavitation photographs of blades at 7000 N.S.S. and 2750 rev/min
66. Cavitation photographs of blades at 10 000 N.S.S. and 2750 rev/min
67. Cavitation sketches of blades at 6000 N.S.S. and 2250 rev/min
68. Cavitation sketches of blades at 7000 N.S.S. and 2250 rev/min
69. Cavitation sketches of blades at full boost pressure and 2750 rev/min
70. Cavitation sketches of blades at 5900 N.S.S. and 2750 rev/min
71. Cavitation sketches of blades at 6000 N.S.S. and 2750 rev/min
72. Cavitation sketches of blades at 6100 N.S.S. and 2750 rev/min
73. Cavitation sketches of blades at 7100 N.S.S. and 2750 rev/min
74. Cavitation sketches of blades at 6900 N.S.S. and 2750 rev/min
75. Cavitation sketches of blades at 6000 N.S.S. and 2750 rev/min.

Antony Spencer

Superintendent

Reference: RY/14/6631

For F. D. PENNY

Director

Date: 12th October, 1967.

COMMERCIAL-IN-CONFIDENCE

DANIEL, MANN, JOHNSON, & MENDENHALL

CONSULTANTS TO DEPARTMENT OF WATER RESOURCES, CALIFORNIA

Tehachapi Bidders Model Tests

Visitor's Statement

I have been delegated as a visitor to this test on behalf of: (Firm's Name)

Metropolitan Water Dist of So Calif

1. I have received copies of the DMJM Specification No. 637-1-2 and the NEL Laboratory Procedure Report for the Tehachapi Bidders Model Tests for my own information on 16 May, 1967.

2. I attended the Observer's Briefing Meeting on 1st to 22nd April, 1967, and the test installation and test procedures were explained to me by the NEL staff and the instrumentation and calibrations were demonstrated. The opportunity was given to me to clarify any points in question.

3. During the N/N Model Tests Jan-Mar 67 several ~~On~~ 1967~~, a~~ demonstration test was performed where I had an opportunity to observe the actual test procedure and operation and I record here my satisfaction with the way those tests are performed.

4. I have been kept informed of the events on the pump test in a general way.

Because of the security requirements involved, which are known to me and which I shall fully observe, I did not have access to the test areas during the official tests nor to any data or calculations thereof. Should any data from these tests come to my knowledge, I shall report this fact to the Chief of Test immediately but will not reveal this knowledge to anyone else.

Signed on Arrival: [illegible]
Date: [illegible]

Resigned on Departure: [illegible]
Date: 28 Aug '67

NOTE: At the time of departure, a line is to be drawn through any statements, 1 to 4, that are not appropriate.

FIG. 1(a) · STATEMENT BY MR. A. WHITSETT

DANIEL, MANN, JOHNSON, & MENDENHALL

CONSULTANTS TO DEPARTMENT OF WATER RESOURCES, CALIFORNIA

Tehachapi Bidders Model Tests

Visitor's Statement

I have been delegated as a visitor to this test on behalf of: (Firm's Name)

Daniel, Mann, Johnson and Mendenhall

1. I have received copies of the DMJM Specification No. 637-1-2 and the NEL Laboratory Procedure Report for the Tehachapi Bidders Model Tests for my own information on 5th April ______________, 1967.

2. ~~I attended the Observer's Briefing Meeting on 1st to 22nd April, 1967, and the test installation and test procedures were explained to me by the NEL staff and the instrumentation and calibrations were demonstrated. The opportunity was given to me to clarify any points in question.~~

3. ~~On ______________, 1967, a demonstration test was performed where I had an opportunity to observe the actual test procedure and operation and I record here my satisfaction with the way those tests are performed.~~

4. I have been kept informed of the events on the pump test in a general way.

Because of the security requirements involved, which are known to me and which I shall fully observe, I did not have access to the test areas during the official tests nor to any data or calculations thereof. Should any data from these tests come to my knowledge, I shall report this fact to the Chief of Test immediately but will not reveal this knowledge to anyone else.

Signed on Arrival: [illegible signature]
Date: July 19-67

Resigned on Departure: [illegible signature]
Date: July 19-67

NOTE: At the time of departure, a line is to be drawn through any statements, 1 to 4, that are not appropriate.

FIG. 1(b) STATEMENT BY MR. S. SVENSON

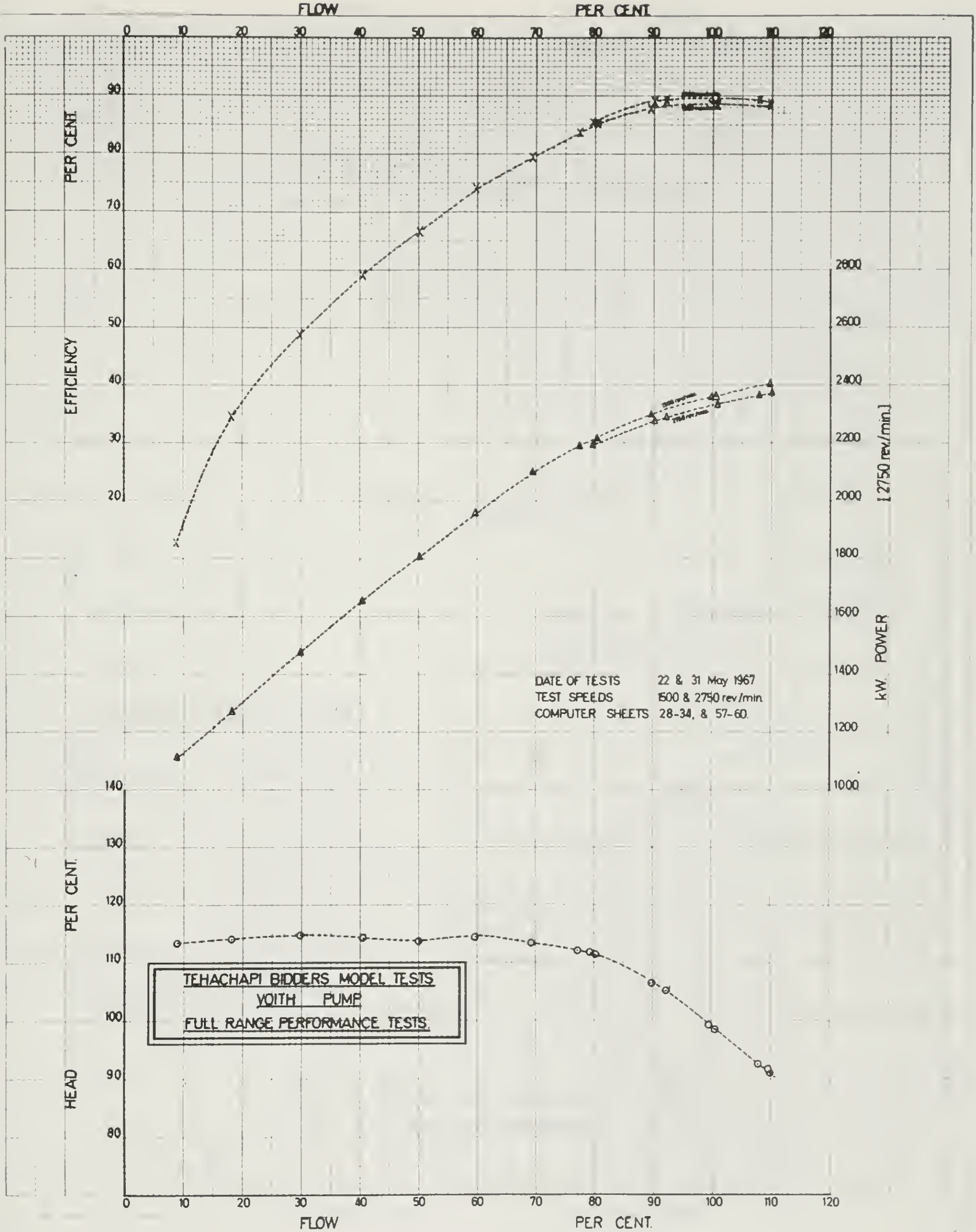

FLOW PER CENT
EFFICIENCY PER CENT
kW. POWER [2750 rev/min.]
HEAD PER CENT.
DATE OF TESTS 22 & 31 May 1967
TEST SPEEDS 1500 & 2750 rev/min.
COMPUTER SHEETS 28-34, & 57-60.
TEHACHAPI BIDDERS MODEL TESTS
VOITH PUMP
FULL RANGE PERFORMANCE TESTS.

FIG 2

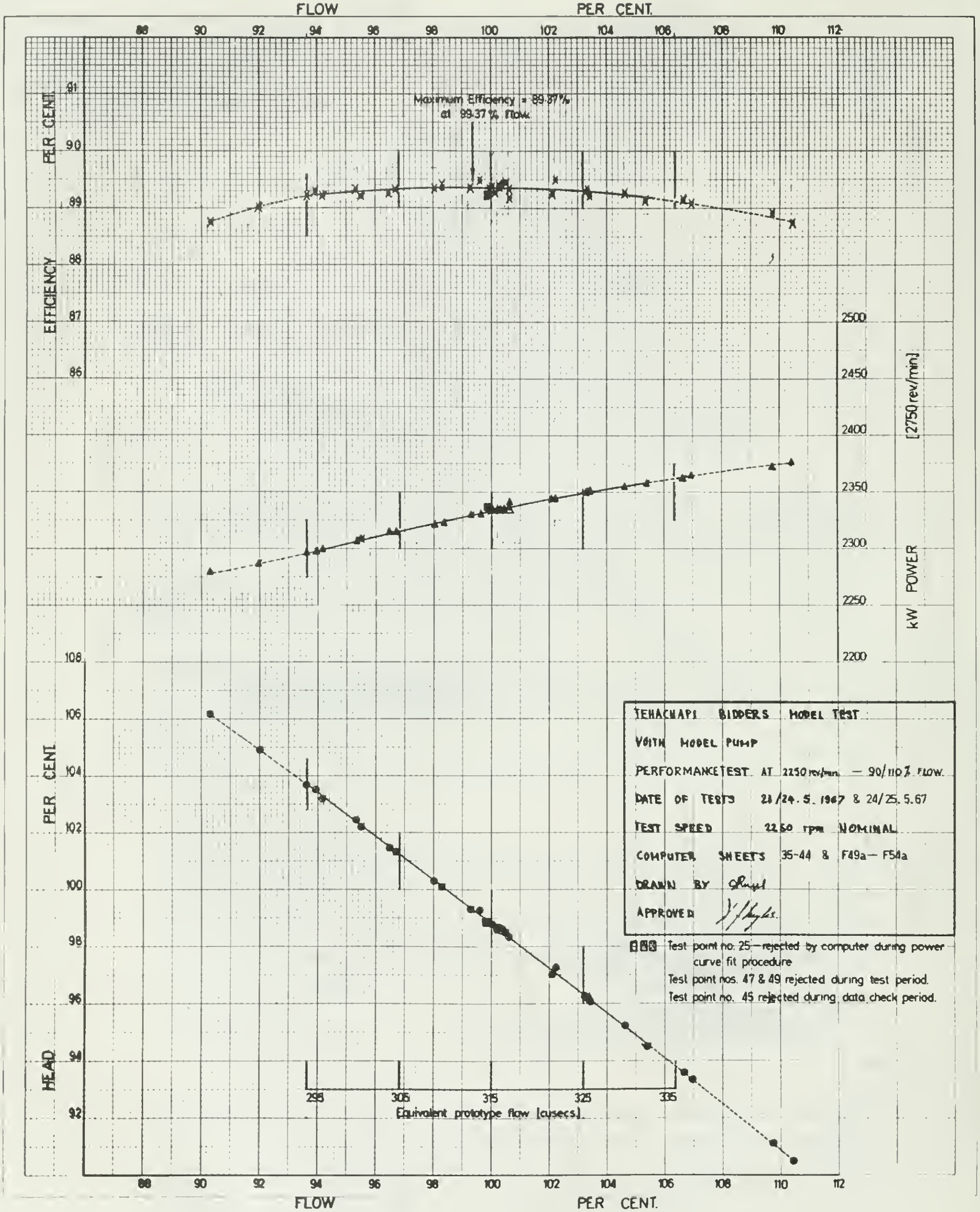

FLOW PER CENT.
Maximum Efficiency = 89.37%
at 99.37% flow.
EFFICIENCY PER CENT
kW POWER
[2750 rev/min]
HEAD PER CENT
Equivalent prototype flow [cusecs]
TEHACHAPI BIDDERS MODEL TEST
VOITH MODEL PUMP
PERFORMANCE TEST AT 2250 rev/min — 90/110% FLOW.
DATE OF TESTS 23/24.5.1967 & 24/25.5.67
TEST SPEED 2250 rpm NOMINAL
COMPUTER SHEETS 35-44 & F49a — F54a
DRAWN BY
APPROVED
Test point no. 25 — rejected by computer during power curve fit procedure
Test point nos. 47 & 49 rejected during test period.
Test point no. 45 rejected during data check period.
FLOW PER CENT.

FIG. 3.

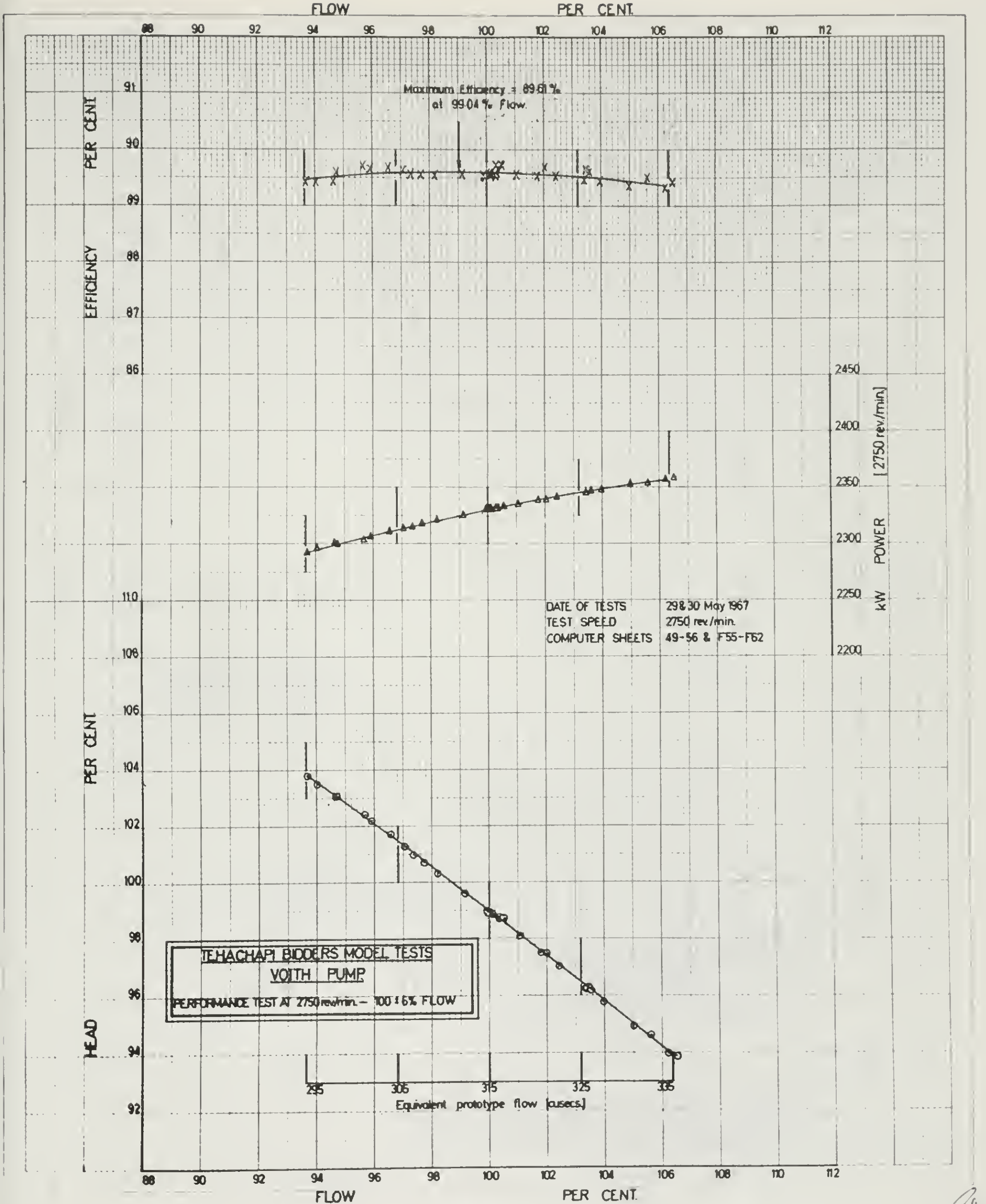

FLOW PER CENT
Maximum Efficiency = 89.61 %
at 99.04 % Flow.
EFFICIENCY PER CENT
kW POWER [2750 rev/min.]
DATE OF TESTS 29 & 30 May 1967
TEST SPEED 2750 rev./min.
COMPUTER SHEETS 49-56 & F55-F62
HEAD PER CENT
TEHACHAPI BIDDERS MODEL TESTS
VOITH PUMP
PERFORMANCE TEST AT 2750 rev/min. – 100 ± 6% FLOW
Equivalent prototype flow (cusecs.)
FLOW PER CENT

FIG. 4.

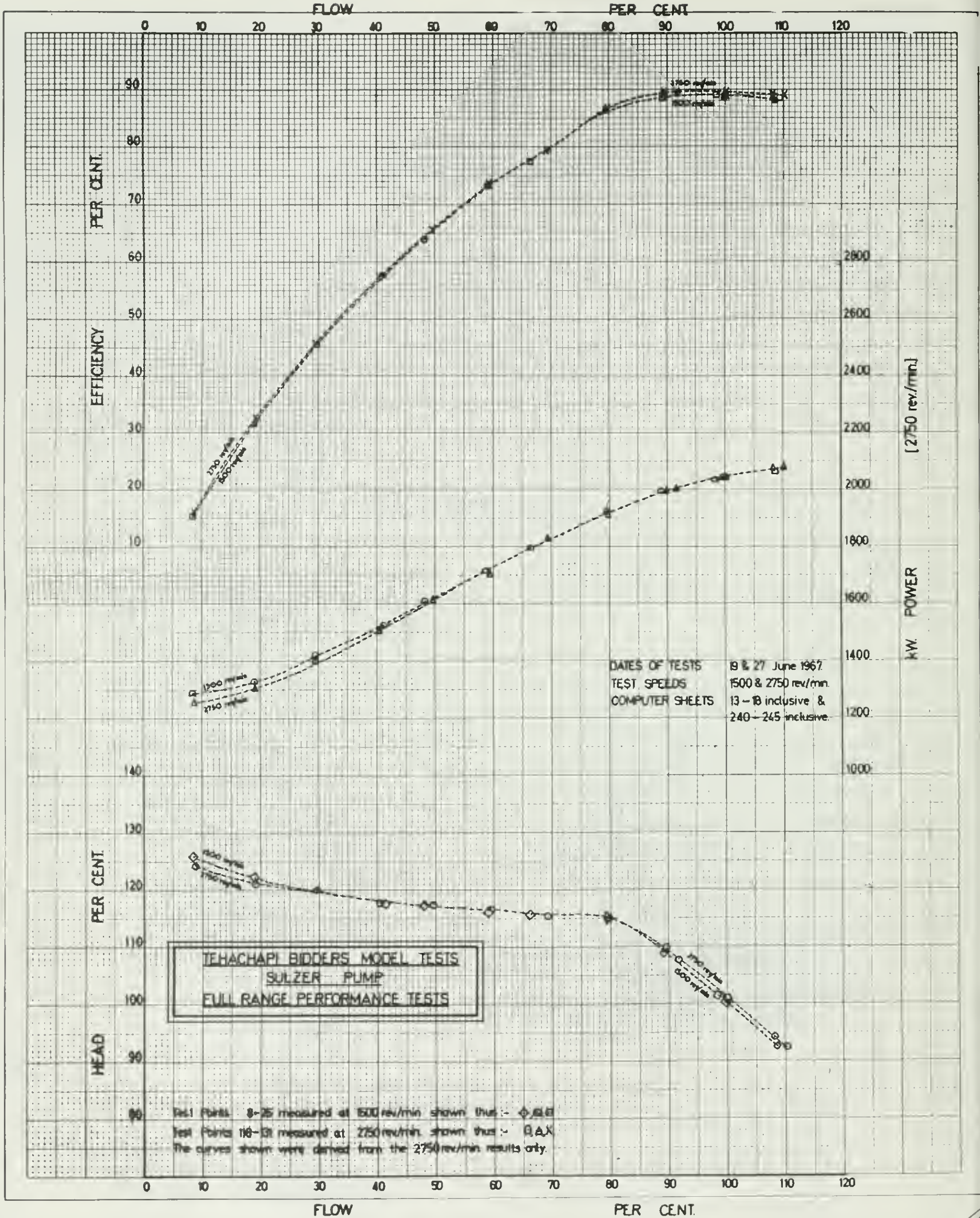
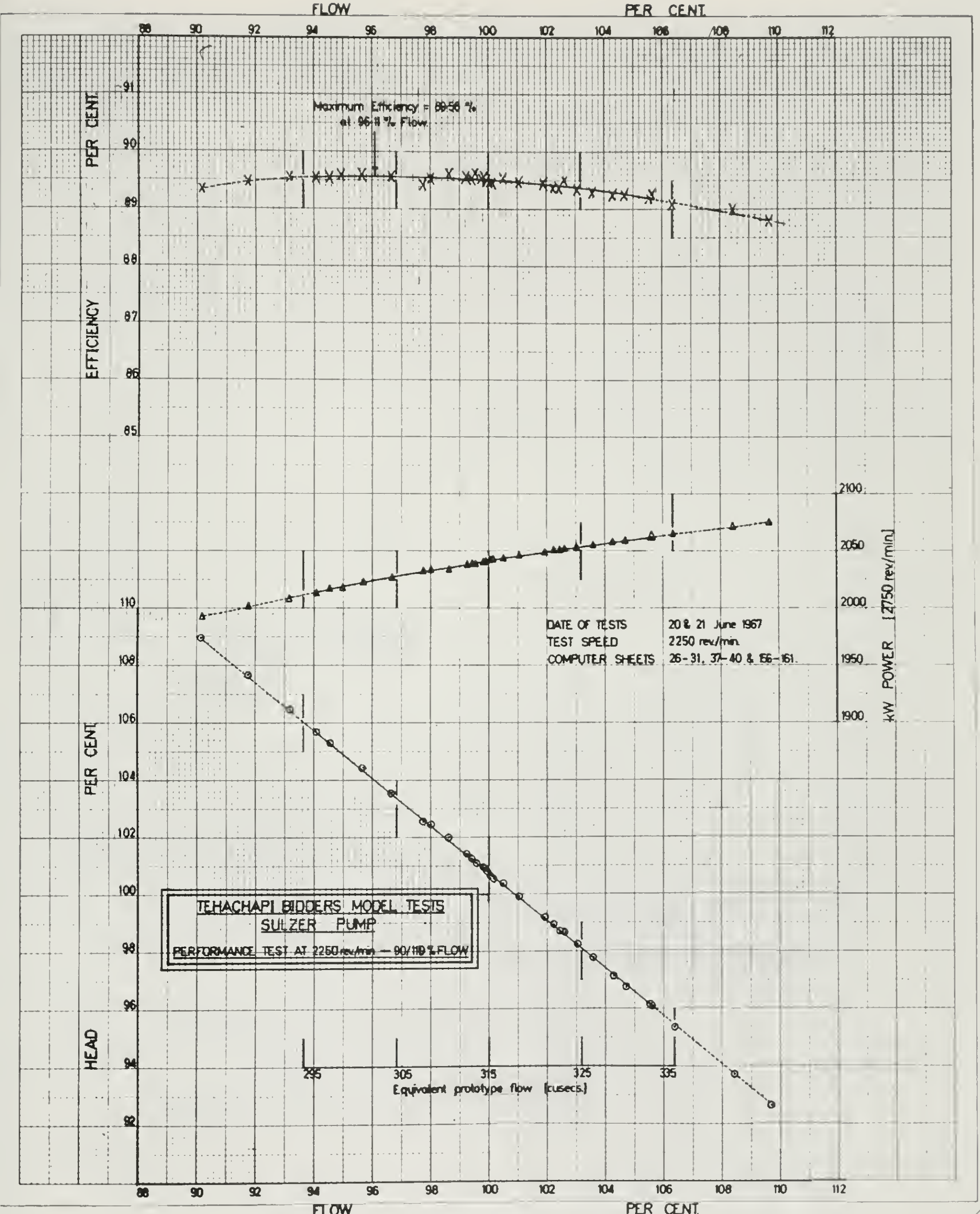
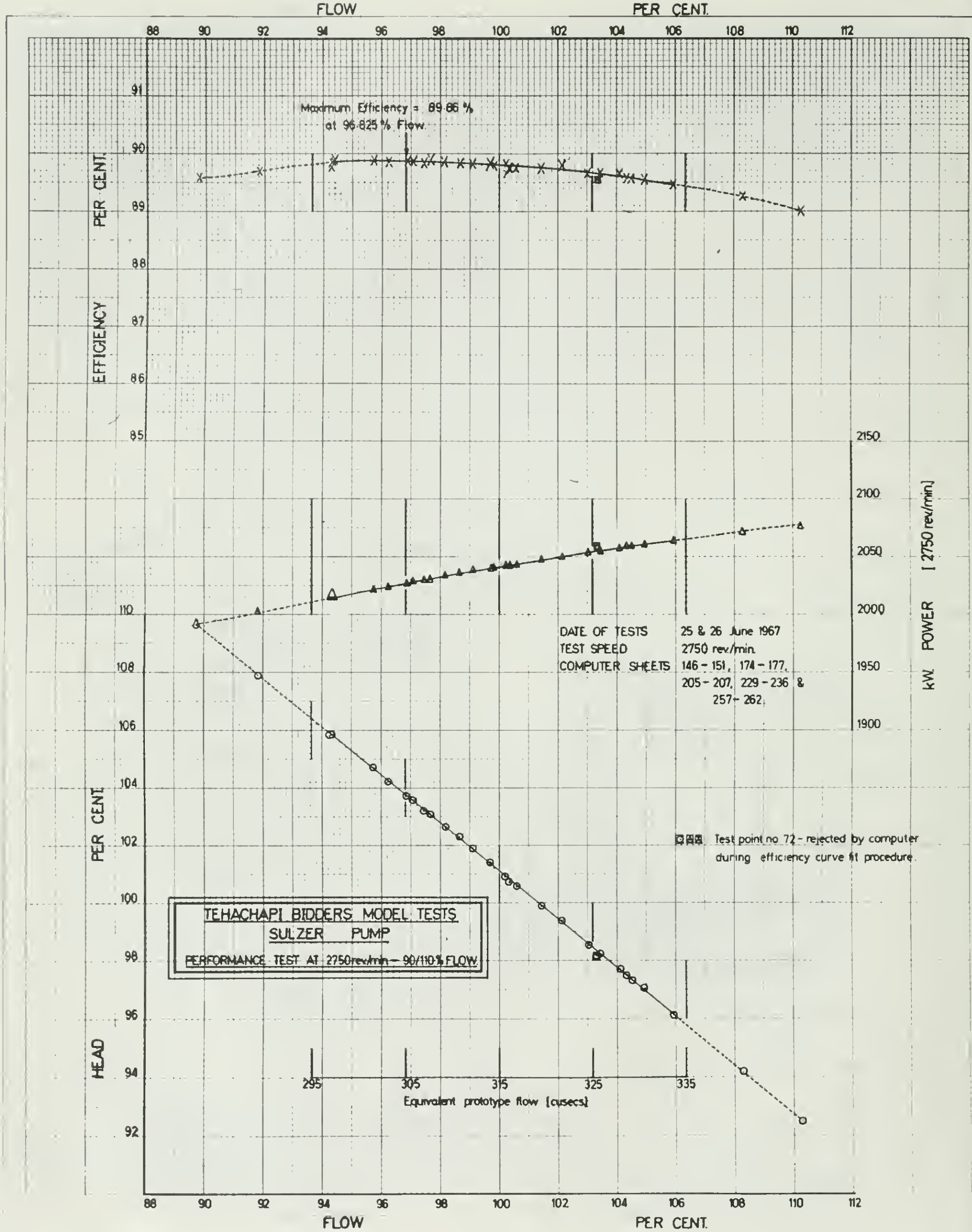

FLOW PER CENT
EFFICIENCY PER CENT
HEAD PER CENT
kW. POWER [2750 rev./min.]
DATES OF TESTS 19 & 27 June 1967
TEST SPEEDS 1500 & 2750 rev/min.
COMPUTER SHEETS 13 – 18 inclusive & 240 – 245 inclusive.
TEHACHAPI BIDDERS MODEL TESTS
SULZER PUMP
FULL RANGE PERFORMANCE TESTS
Test Points 8–26 measured at 1500 rev/min. shown thus :-
Test Points 118–131 measured at 2750 rev/min. shown thus :-
The curves shown were derived from the 2750 rev/min. results only.

FIG. 5.



FLOW
PER CENT
Maximum Efficiency = 89.56 %
at 96.11 % Flow
EFFICIENCY PER CENT
HEAD PER CENT
kW POWER [2750 rev/min]
DATE OF TESTS 20 & 21 June 1967
TEST SPEED 2250 rev/min.
COMPUTER SHEETS 26-31, 37-40 & 156-161.
TEHACHAPI BIDDERS MODEL TESTS
SULZER PUMP
PERFORMANCE TEST AT 2250 rev/min — 90/110 % FLOW
Equivalent prototype flow [cusecs]

FIG. 6.



FLOW PER CENT.
Maximum Efficiency = 89.86 %
at 96.825 % Flow.
EFFICIENCY PER CENT.
kW POWER [2750 rev/min]
DATE OF TESTS 25 & 26 June 1967
TEST SPEED 2750 rev/min.
COMPUTER SHEETS 146 - 151, 174 - 177, 205 - 207, 229 - 236 & 257 - 262.
Test point no 72 - rejected by computer during efficiency curve fit procedure.
HEAD PER CENT.
TEHACHAPI BIDDERS MODEL TESTS
SULZER PUMP
PERFORMANCE TEST AT 2750 rev/min - 90/110 % FLOW.
Equivalent prototype flow [cusecs]
FLOW PER CENT.

FIG. 7.

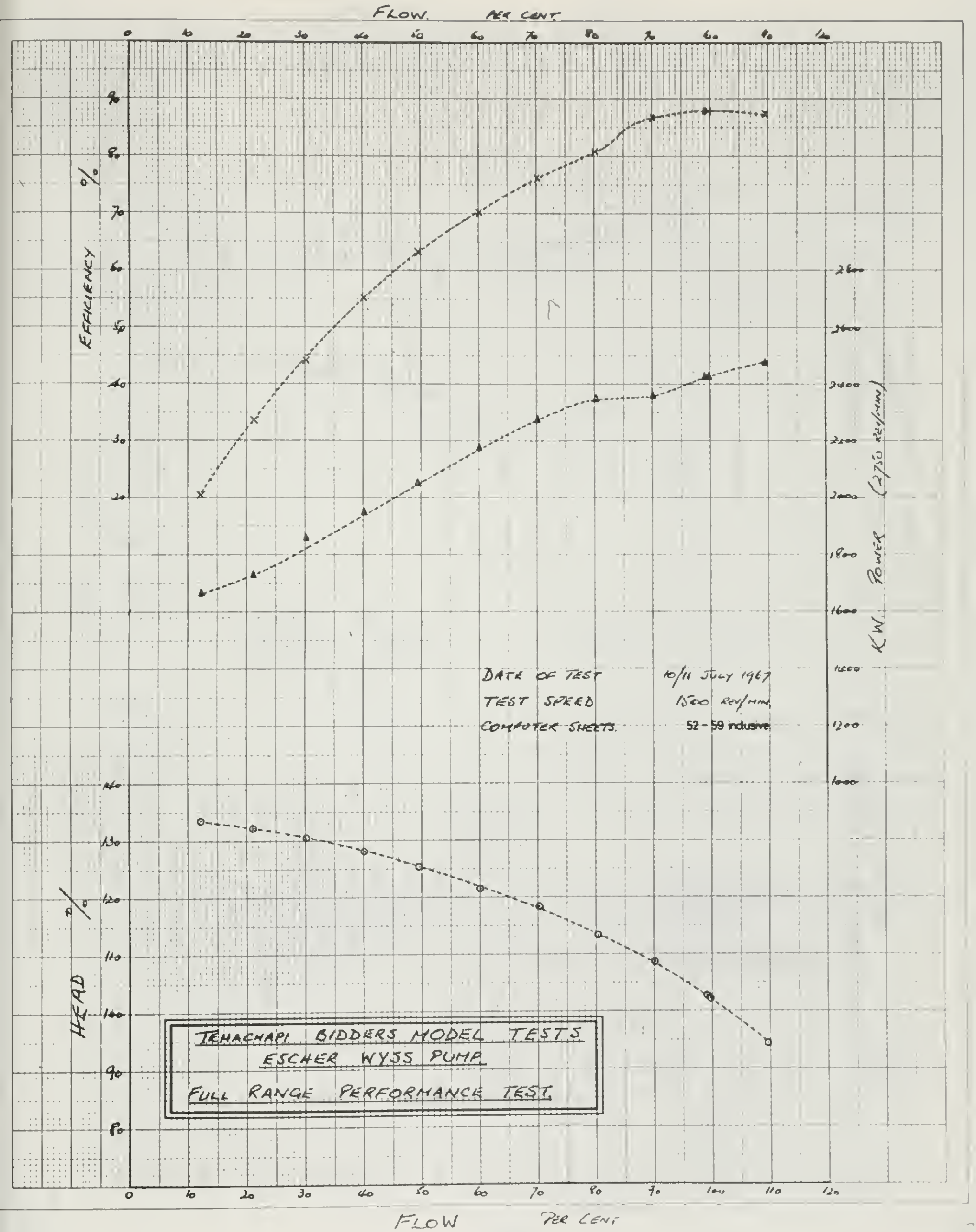

FLOW PER CENT
EFFICIENCY %
KW. POWER (2750 REV/MIN)
HEAD %
DATE OF TEST 10/11 JULY 1967
TEST SPEED 1500 REV/MIN
COMPUTER SHEETS 52 - 59 inclusive
TEHACHAPI BIDDERS MODEL TESTS
ESCHER WYSS PUMP
FULL RANGE PERFORMANCE TEST
FLOW PER CENT

FIG. 8.

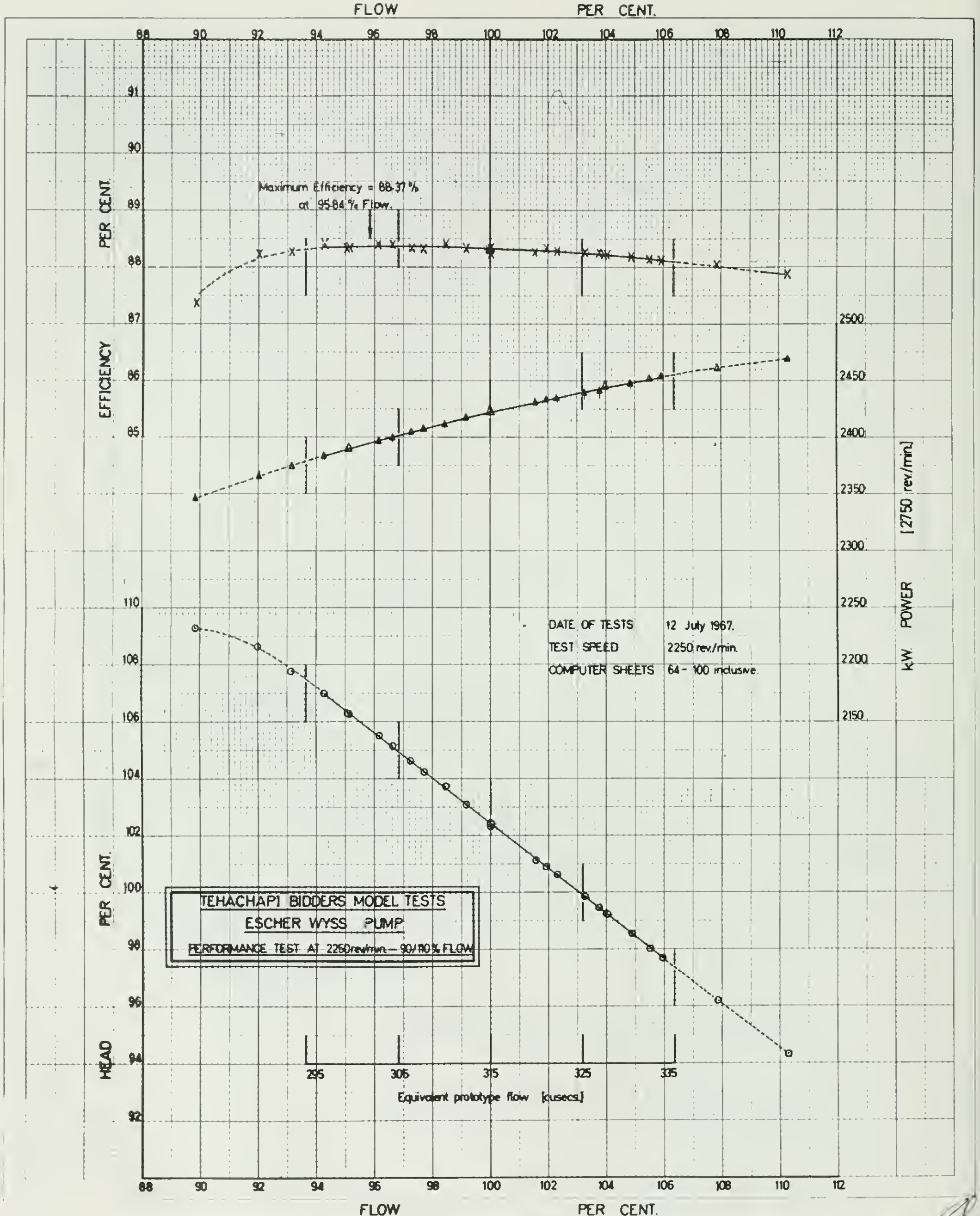
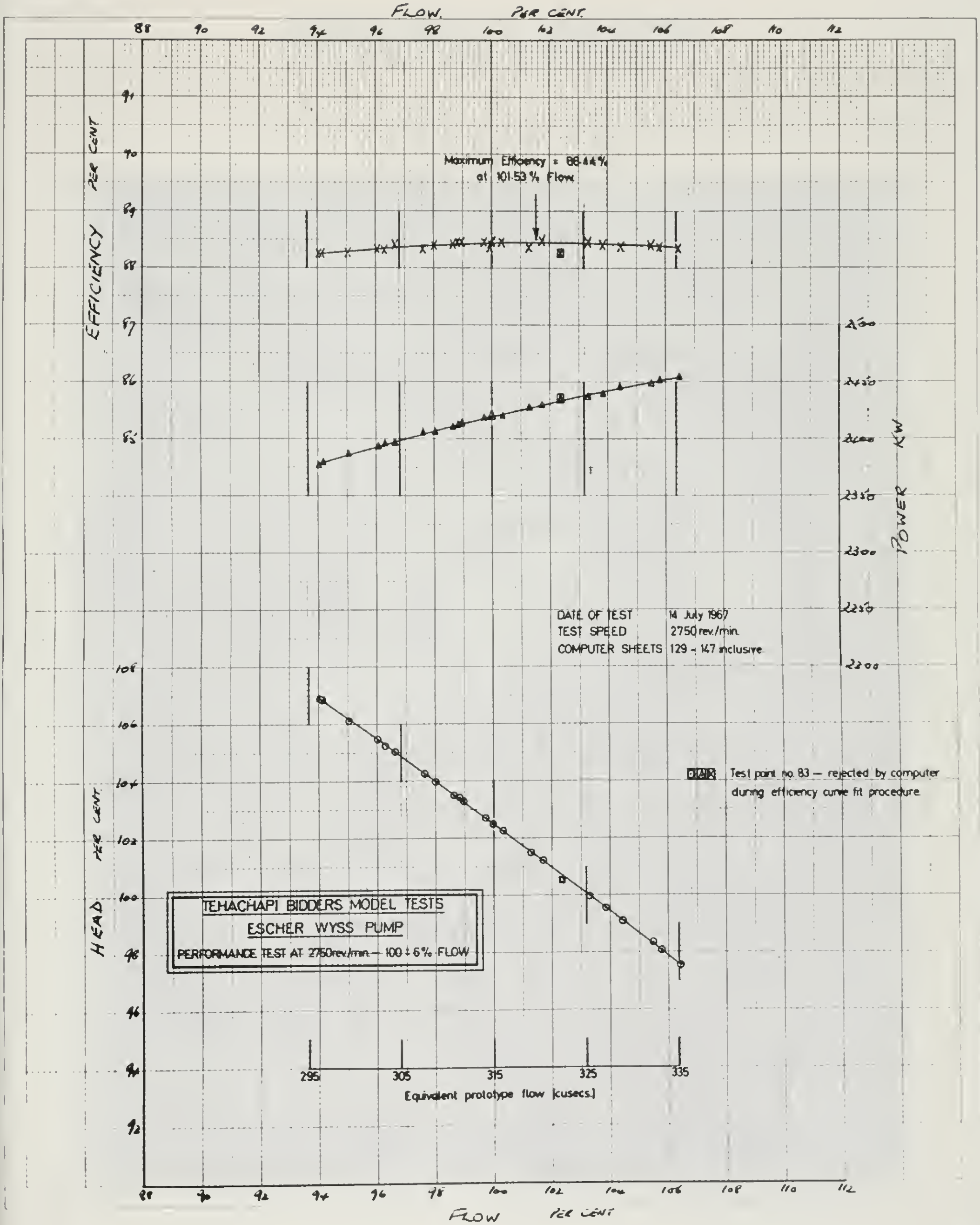

FLOW PER CENT.
Maximum Efficiency = 88.37 %
at 95.84 % Flow.
EFFICIENCY PER CENT.
HEAD PER CENT.
kW. POWER [2750 rev./min.]
DATE OF TESTS 12 July 1967.
TEST SPEED 2250 rev./min.
COMPUTER SHEETS 64 - 100 inclusive.
TEHACHAPI BIDDERS MODEL TESTS
ESCHER WYSS PUMP
PERFORMANCE TEST AT 2250 rev/min. - 90/110 % FLOW
Equivalent prototype flow [cusecs.]

FIG. 9.



FLOW PER CENT
EFFICIENCY PER CENT
POWER KW
HEAD PER CENT
Maximum Efficiency = 88.44%
at 101.53% Flow
DATE OF TEST 14 July 1967
TEST SPEED 2750 rev./min.
COMPUTER SHEETS 129 - 147 inclusive
Test point no. 83 — rejected by computer during efficiency curve fit procedure.
TEHACHAPI BIDDERS MODEL TESTS
ESCHER WYSS PUMP
PERFORMANCE TEST AT 2750 rev./min. — 100 ± 6% FLOW
Equivalent prototype flow (cusecs.)

FIG. 10.

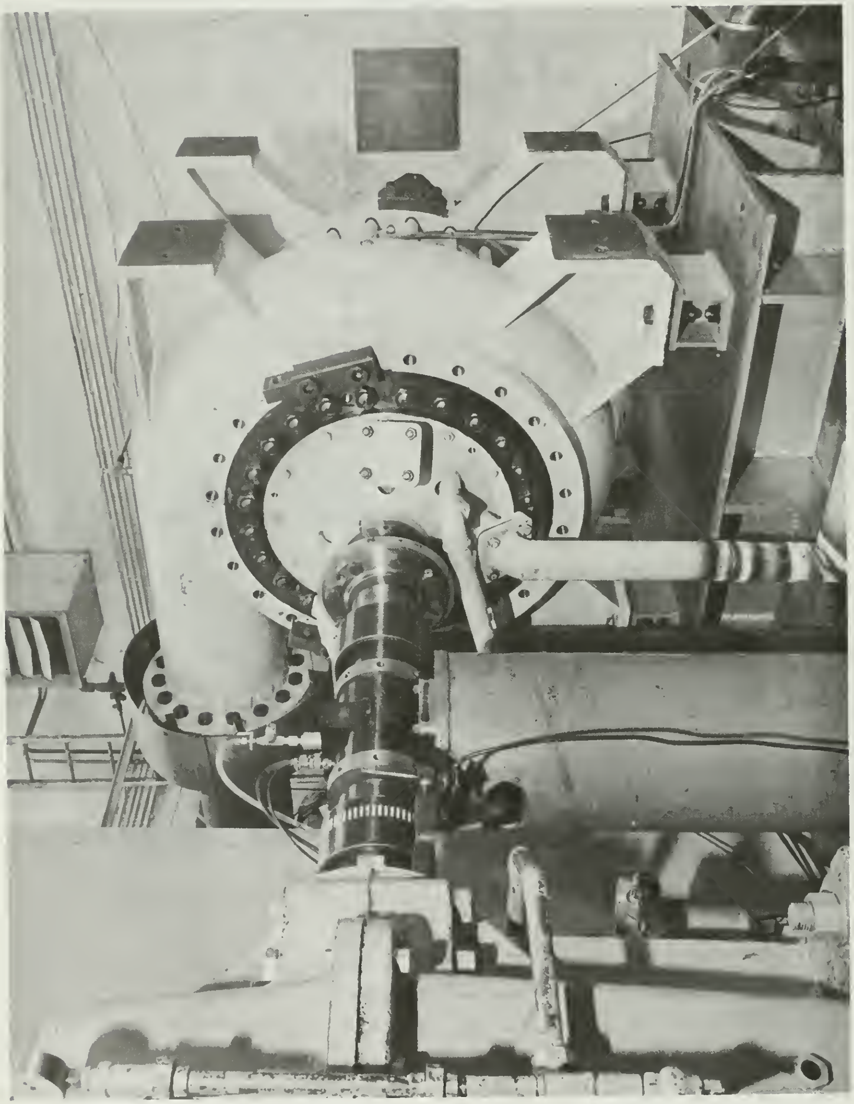


FIG. 11. MODEL PUMP ON TEST STAND
(VOITH)

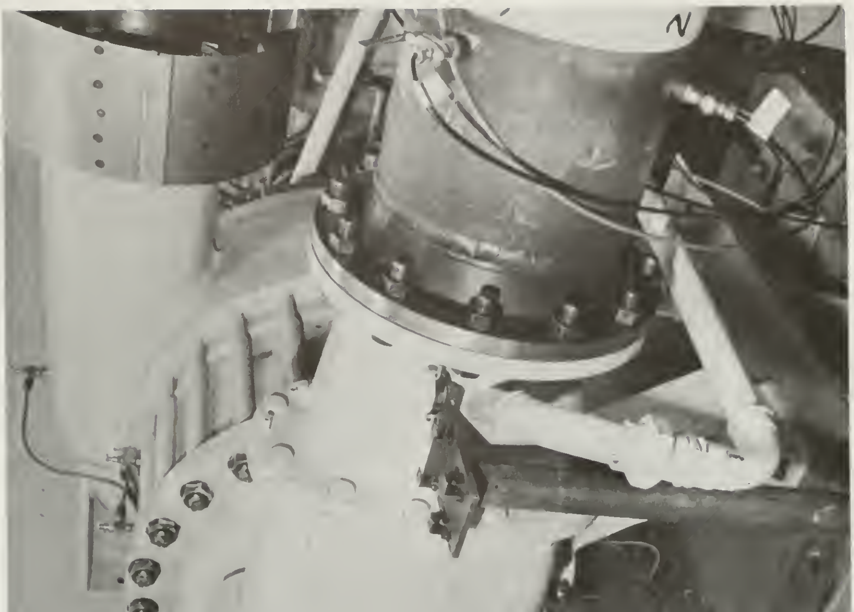


FIG. 12. OBSERVATION WINDOWS IN MODEL PUMP
(VOITH)

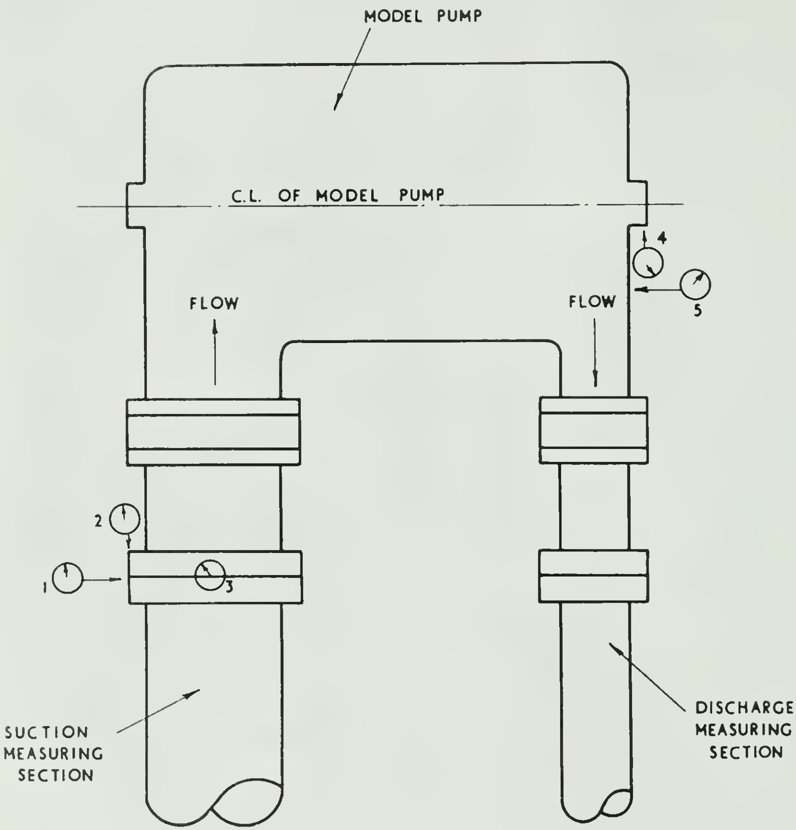


FIG.13 SKETCH SHOWING POSITION OF CLOCK GAUGES USED TO CHECK VIBRATION OF MODEL PUMP WHEN RUNNING

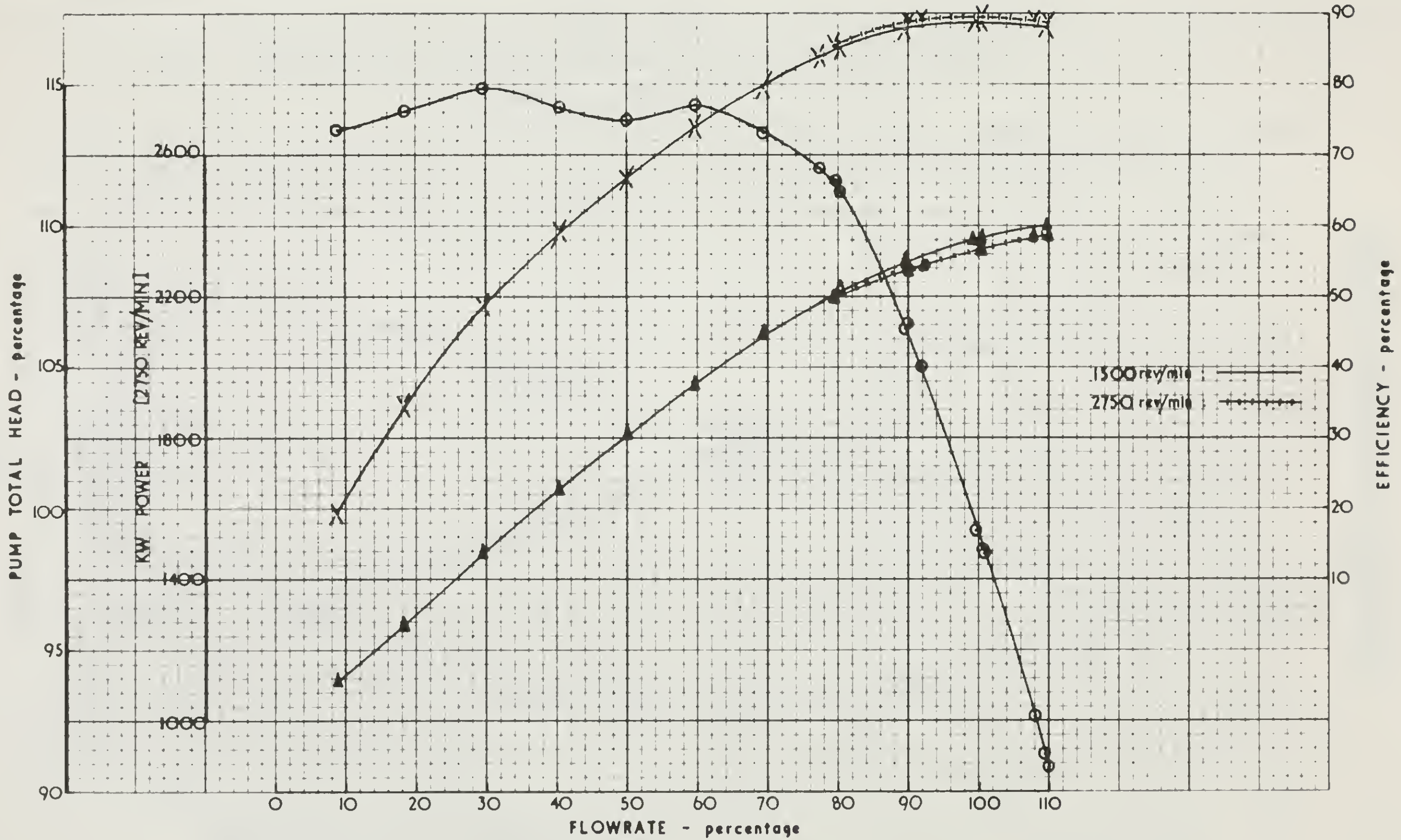


FIG.14. TEST SERIES 2 AND 4c CHARACTERISTICS OF MODEL AT 1500 AND 2750 REV/MIN
VOITH PUMP

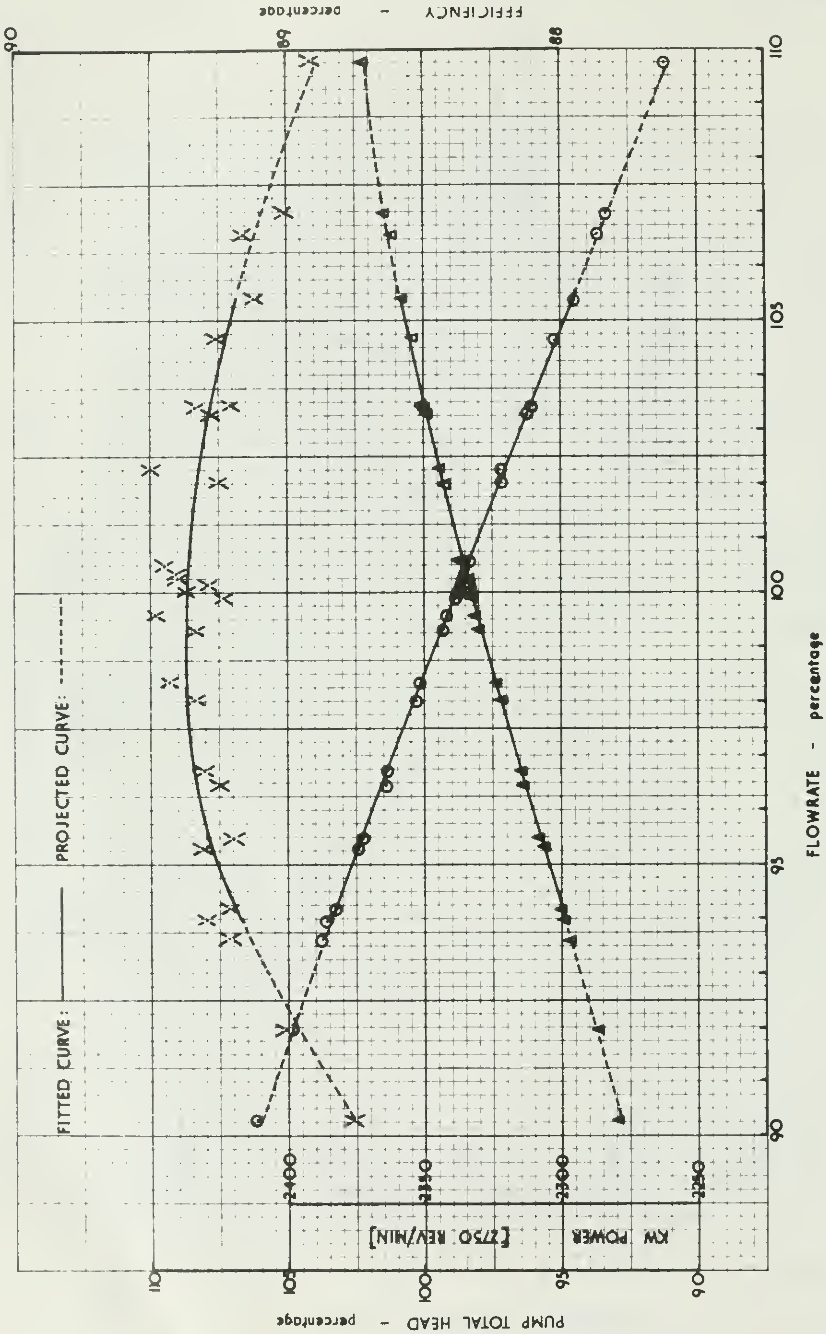


FIG.15. TEST SERIES 3a&b CHARACTERISTICS OF MODEL AT 2250 REV/MIN VOITH PUMP

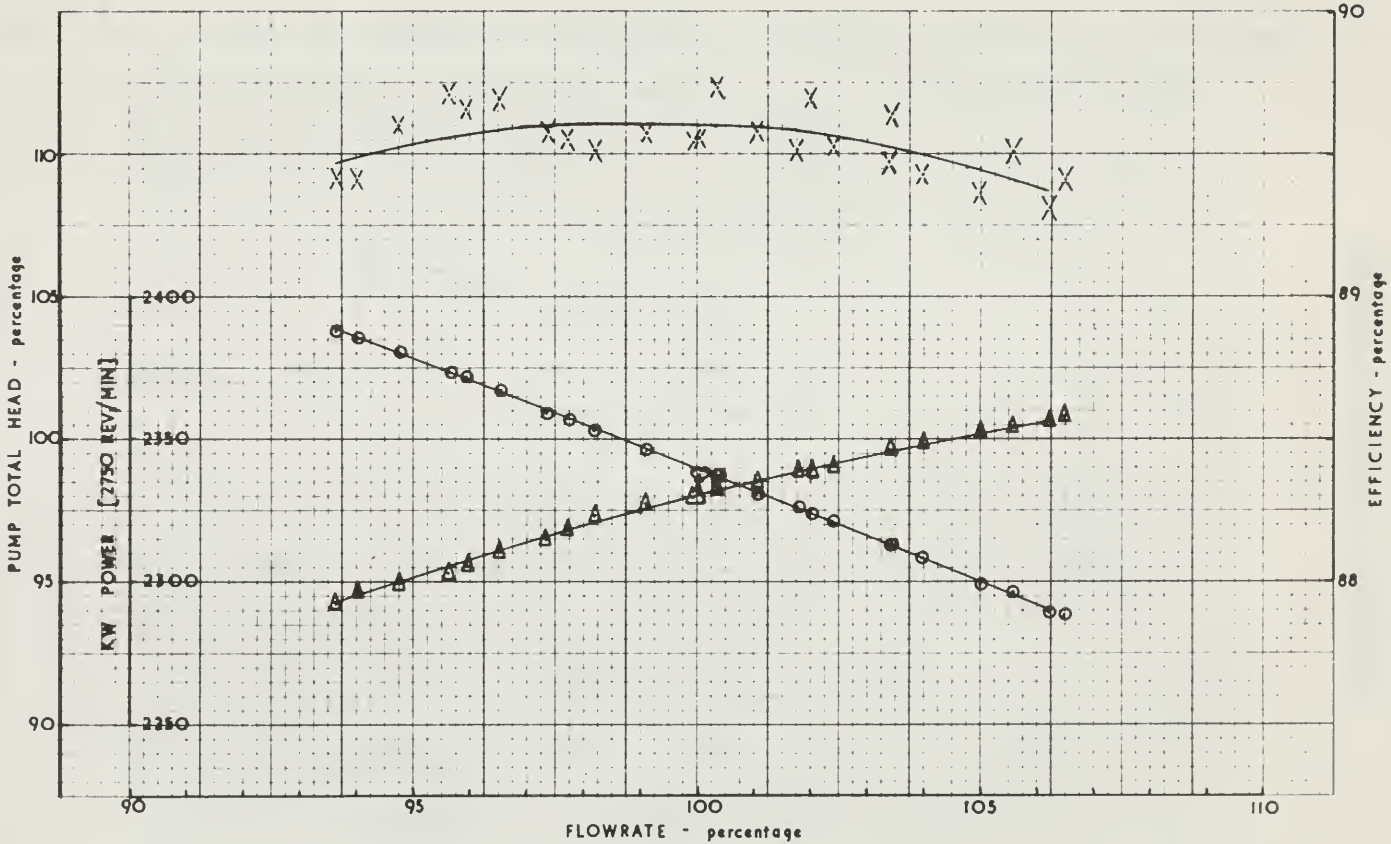


FIG.16. TEST SERIES 4a CHARACTERISTICS OF MODEL AT 2750 REV/MIN VOITH PUMP

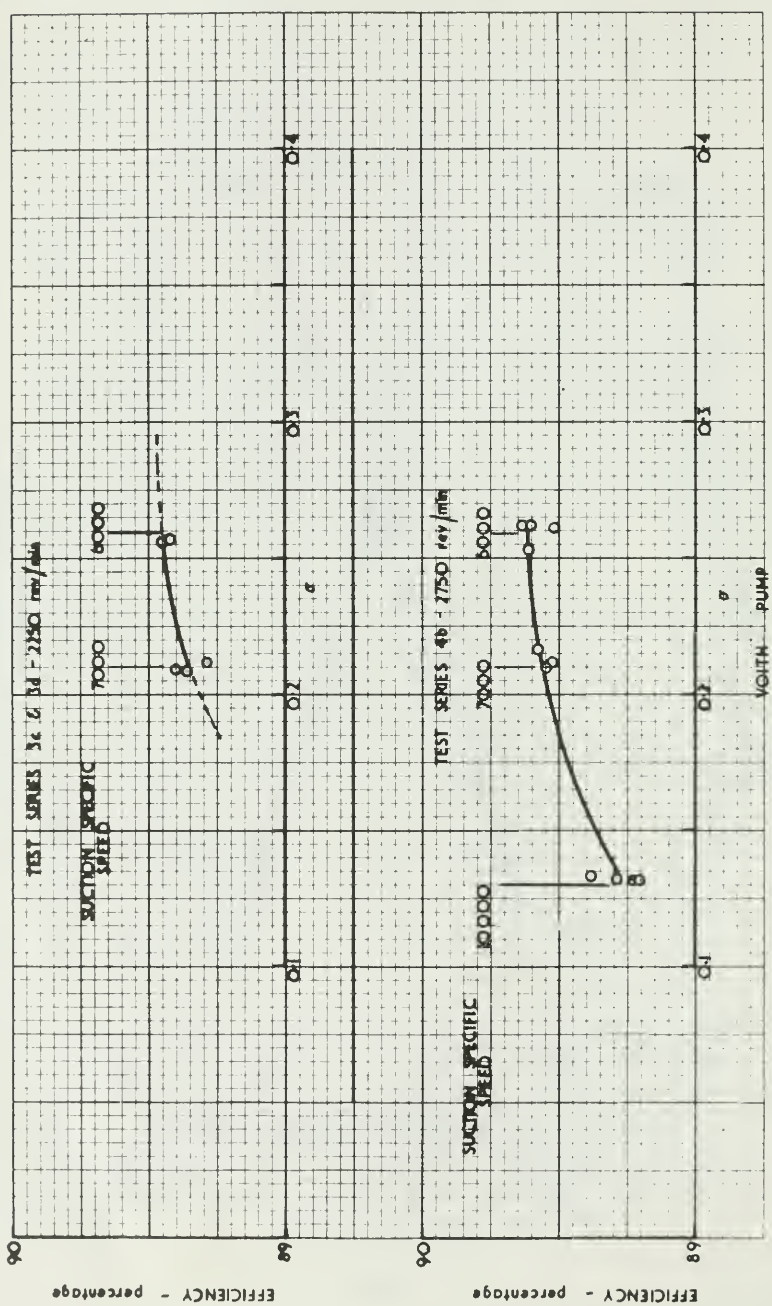


FIG 17 TEST SERIES 3c, 3d AND 4b CAVITATION CHARACTERISTICS OF MODEL AT 2250 AND 2750 REV/MIN

Figures 18 through 27 of the original report have been deleted for purposes of this publication. The information shown is considered proprietary by the pump manufacturer involved.

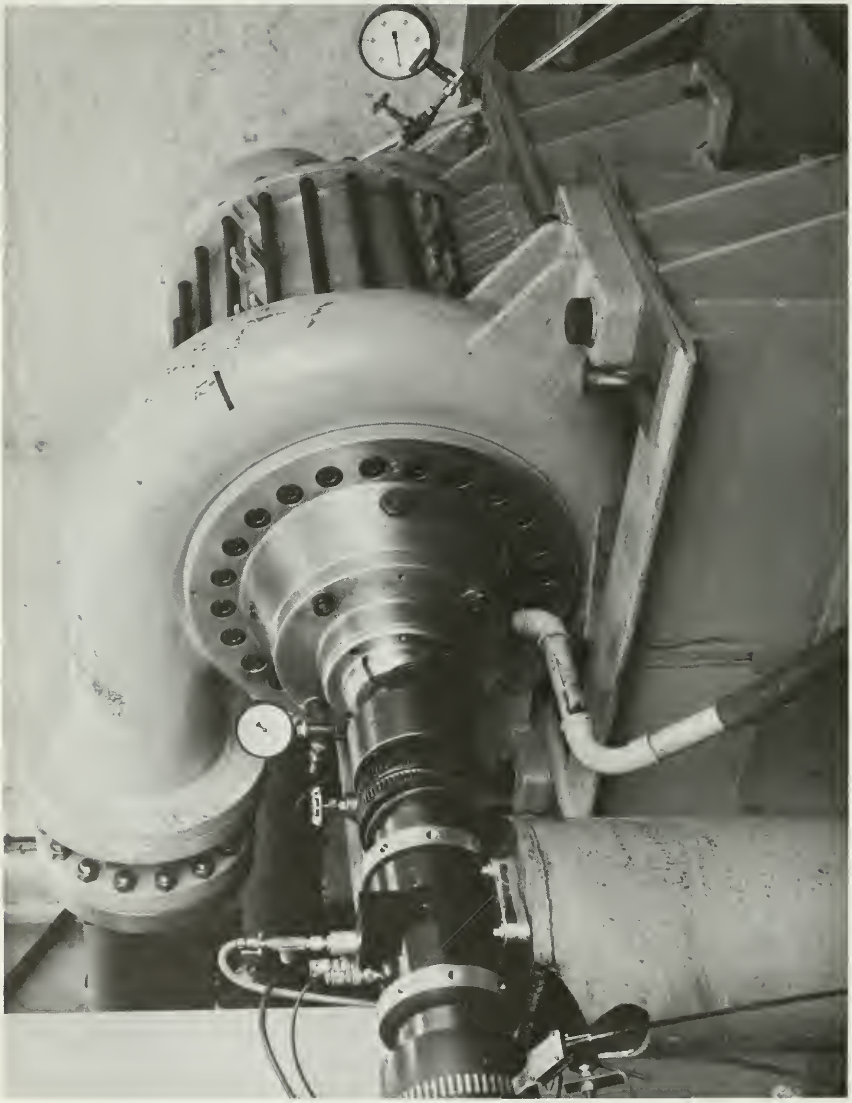


FIG. 28. MODEL PUMP ON TEST STAND
(SULZER)

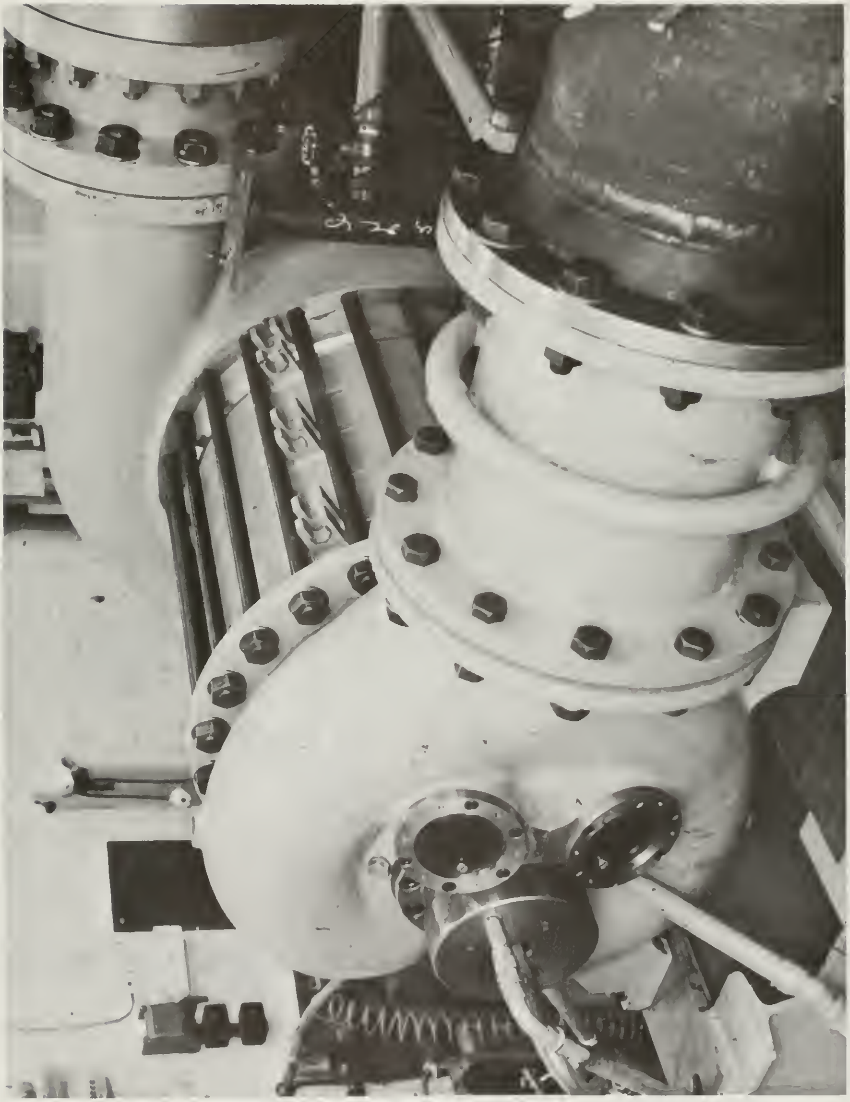


FIG. 29. OBSERVATION WINDOWS IN MODEL PUMP
(SULZER)

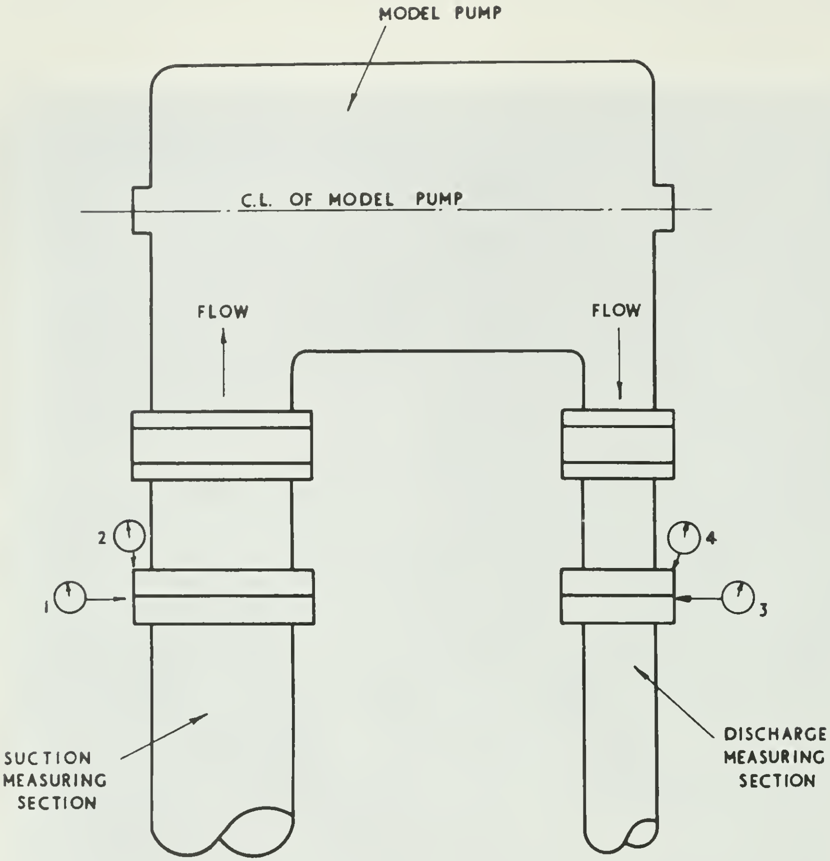


FIG 30 SKETCH SHOWING POSITION OF CLOCK GAUGES USED TO CHECK VIBRATION OF MODEL PUMP WHEN RUNNING

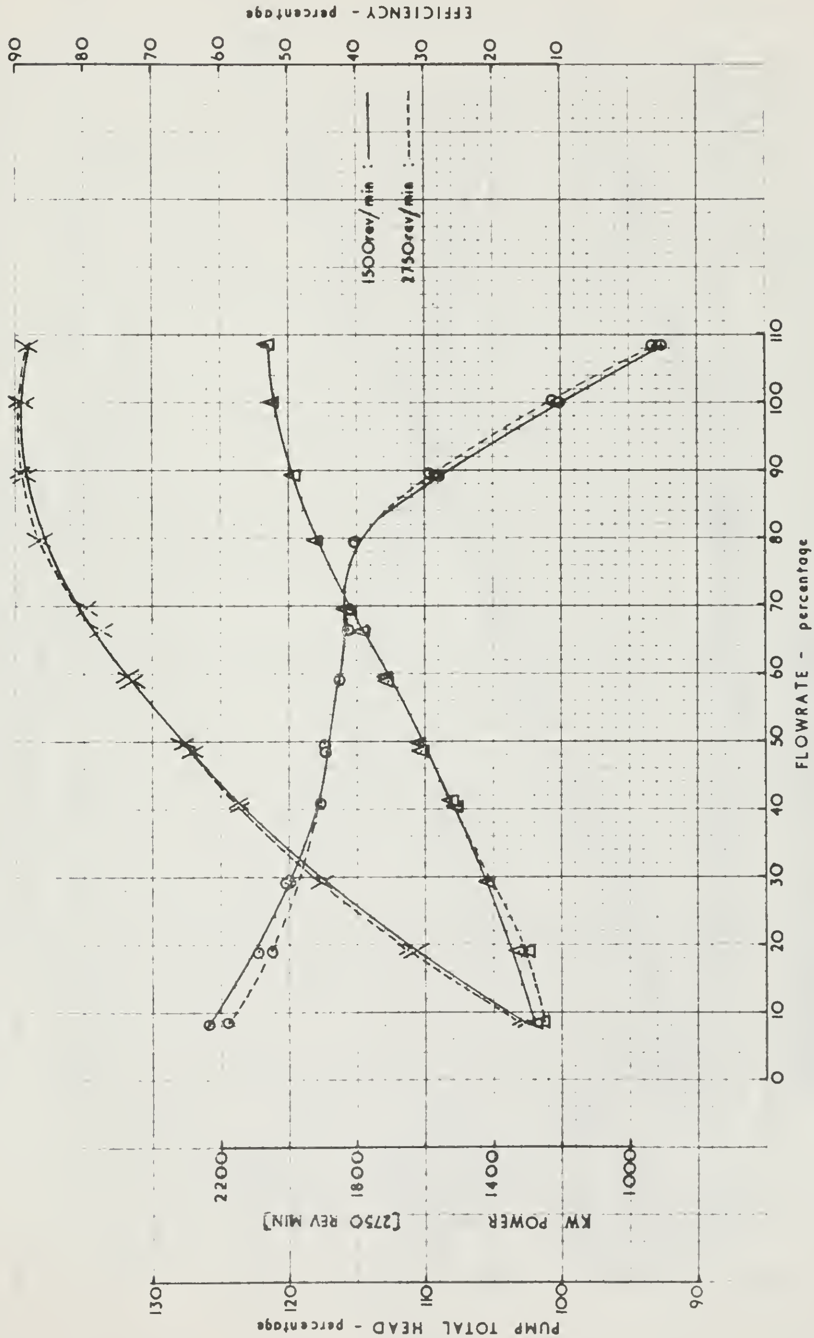


FIG.31 TEST SERIES 2 AND 4c CHARACTERISTICS OF MODEL AT 1500 AND 2750 REV/MIN SULZER PUMP

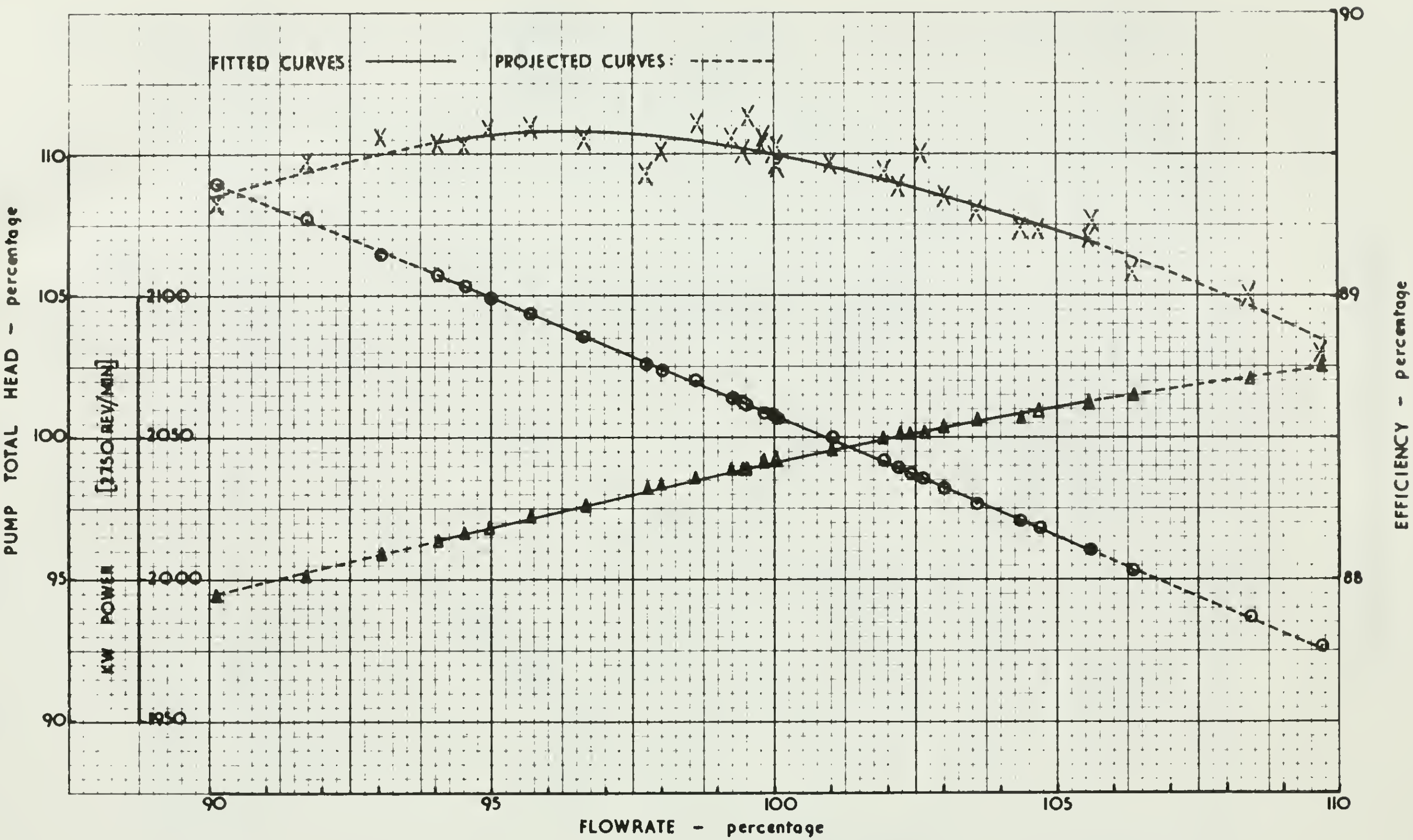


FIG. 32. TEST SERIES 3a & b CHARACTERISTICS OF MODEL AT 2250 REV/MIN SULZER PUMP

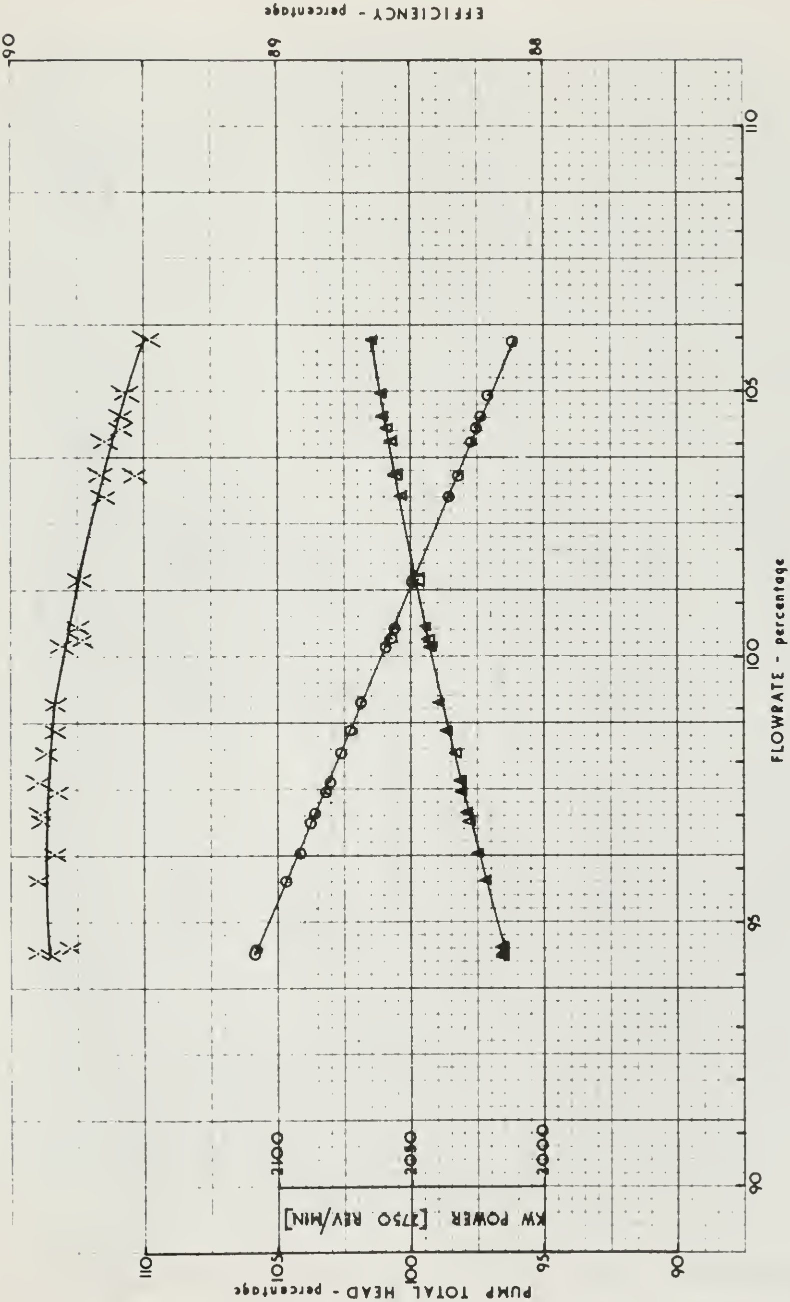


FIG.33. TEST SERIES 4a CHARACTERISTICS OF MODEL AT 2750 REV/MIN SULZER PUMP

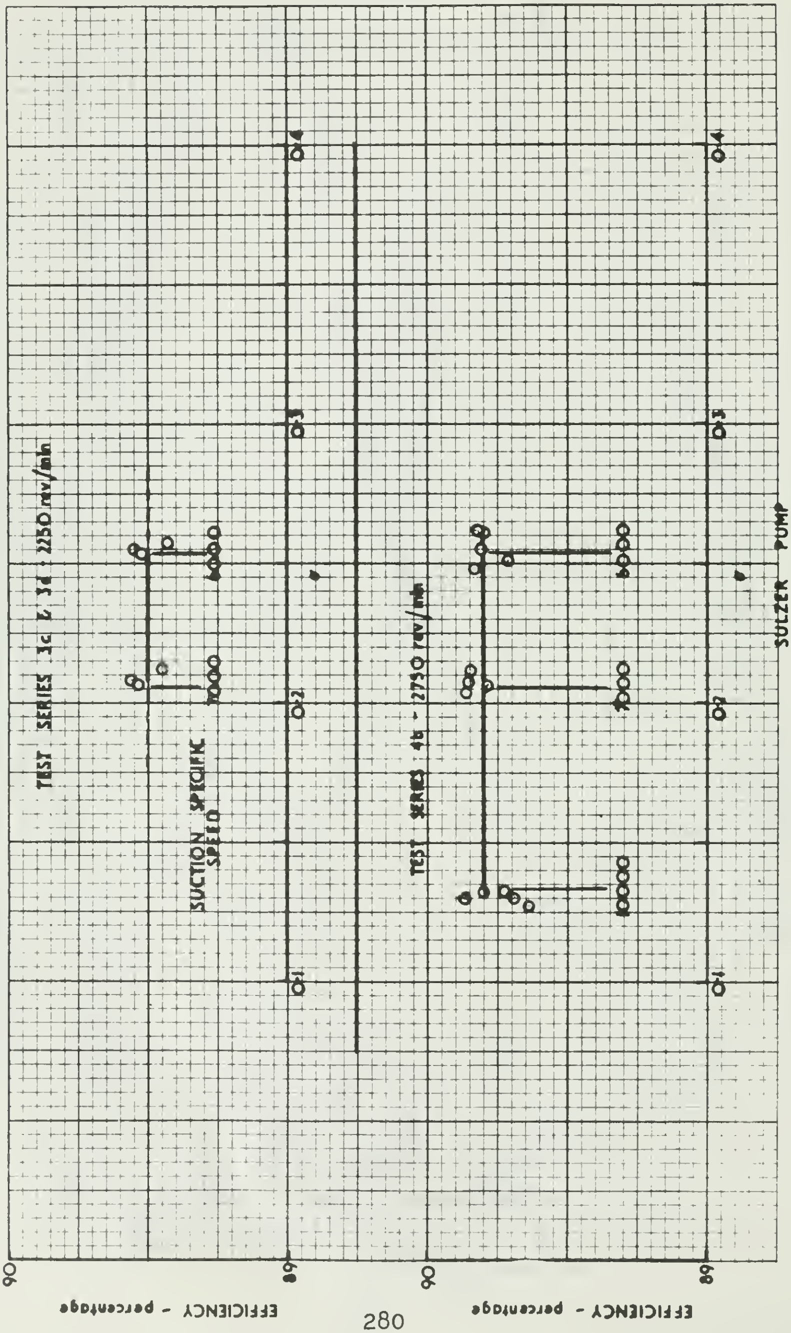


FIG 34 TEST SERIES 3c, 3d AND 4b CAVITATION CHARACTERISTICS OF MODEL AT 2250 AND 2750 REV/MIN

Figures 35 through 53 of the original report have been deleted for purposes of this publication. The information shown is considered proprietary by the pump manufacturer involved.

3. 54. MODEL PUMP ON TEST STAND
(ESCHER WYSS)

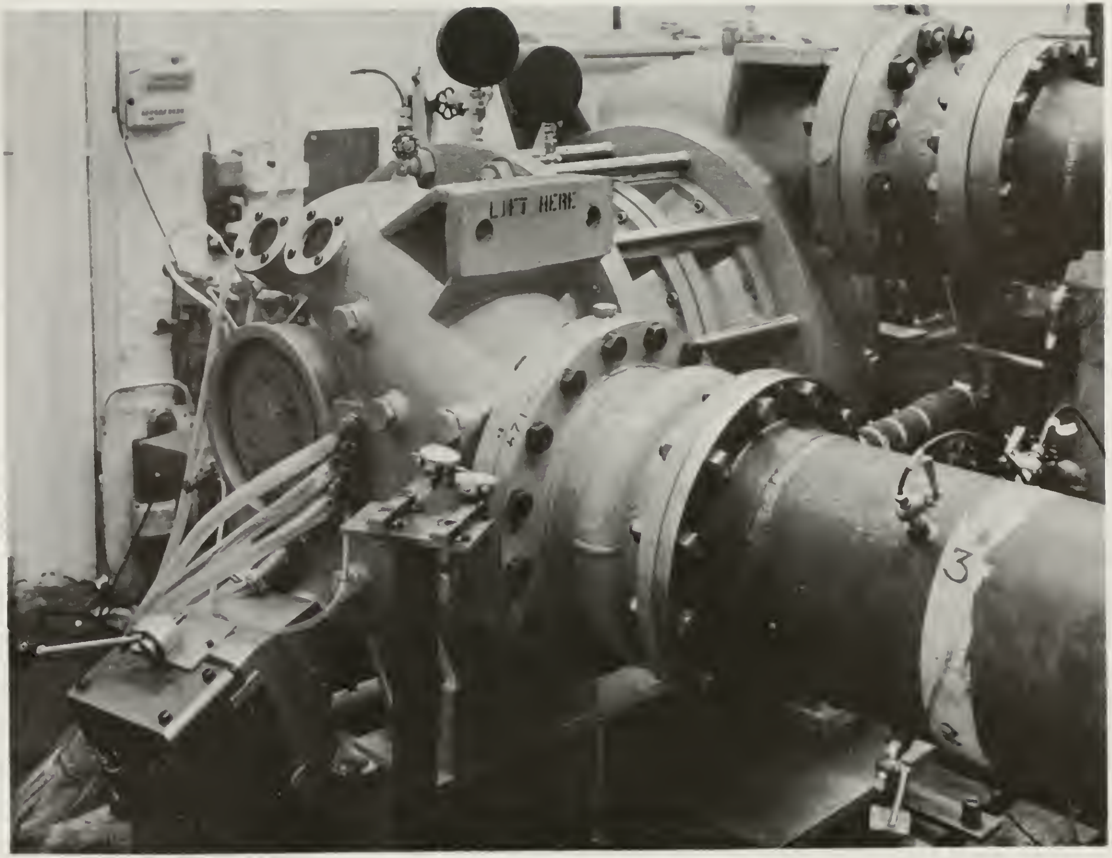


FIG. 55. OBSERVATION WINDOWS IN MODEL PUMP
(ESCHER WYSS)

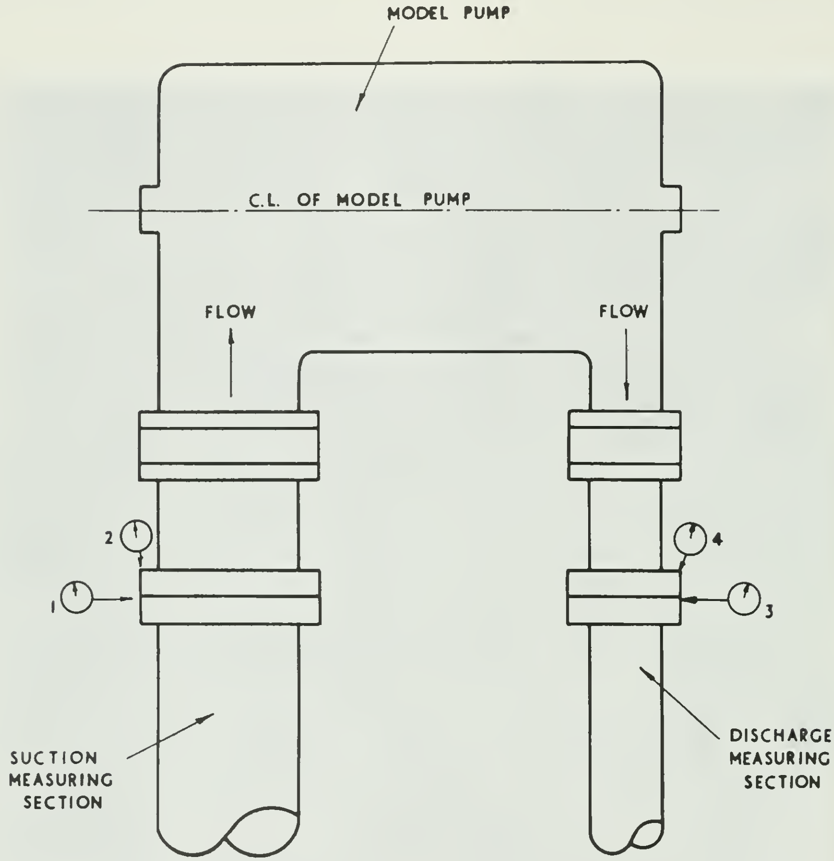
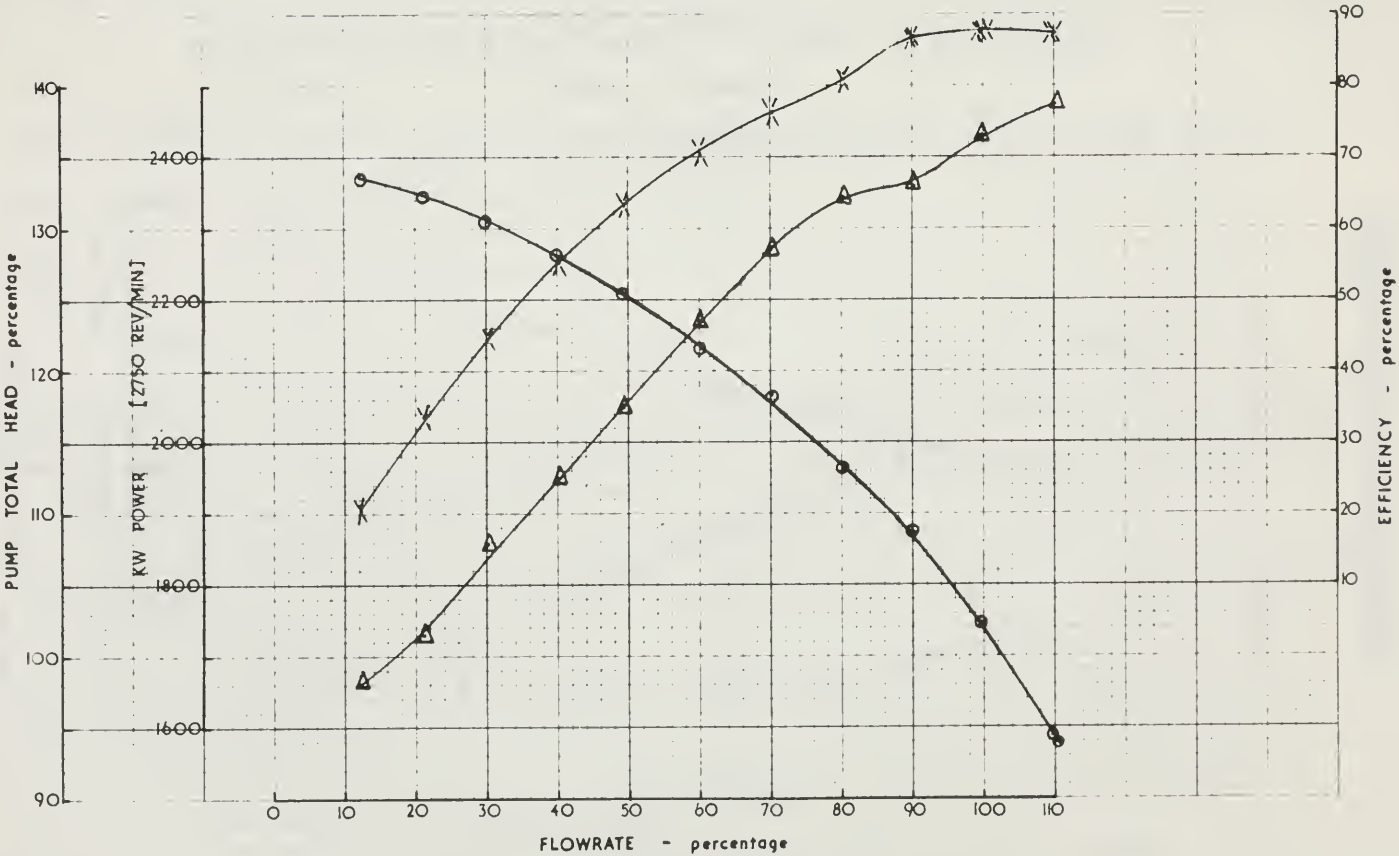


FIG 56 SKETCH SHOWING POSITION OF CLOCK GAUGES USED TO CHECK VIBRATION OF MODEL PUMP WHEN RUNNING



ESCHER WYSS PUMP

FIG.57 TEST SERIES 2. CHARACTERISTICS OF MODEL AT 1500 REV/MIN

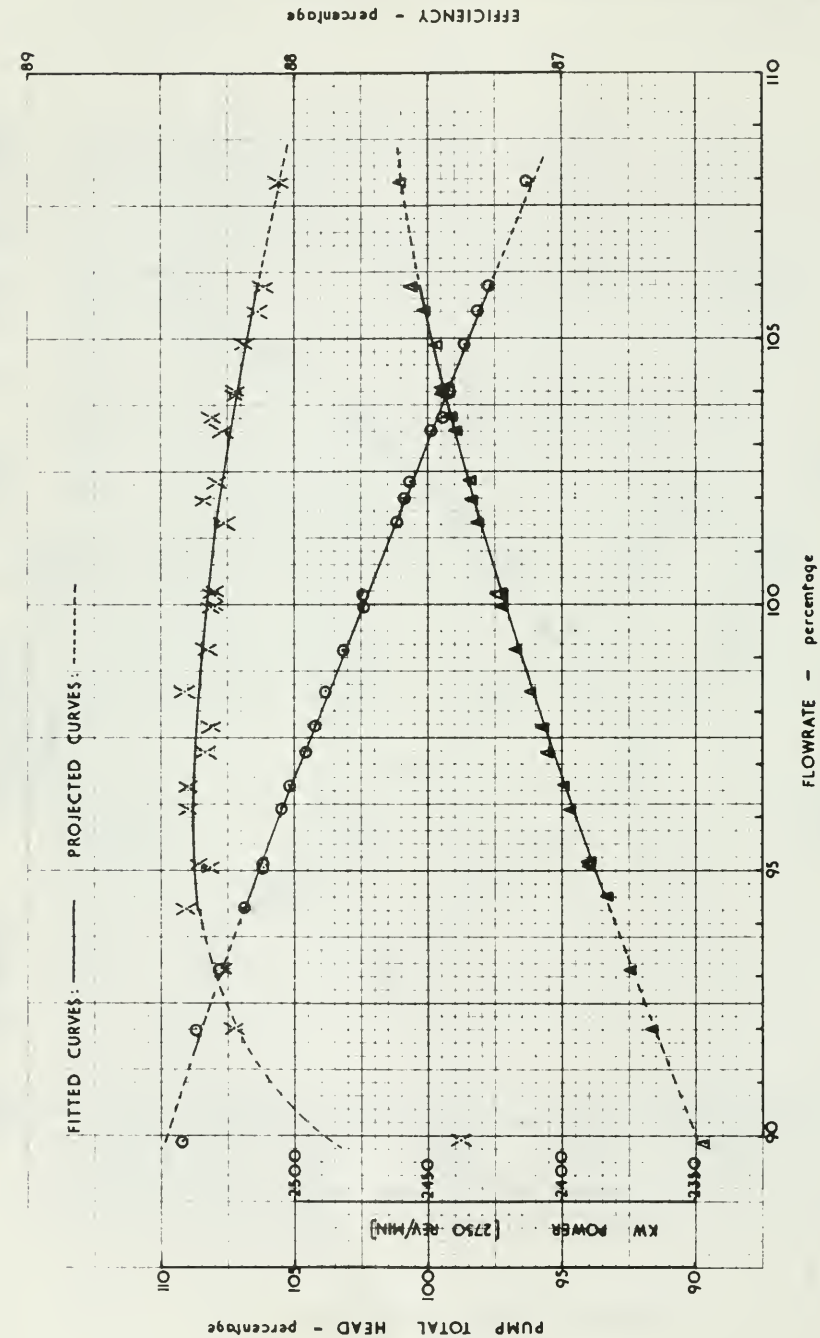


FIG.58. TEST SERIES 3a&b CHARACTERISTICS OF MODEL AT 2250 REV/MIN
ESCHER WYSS PUMP

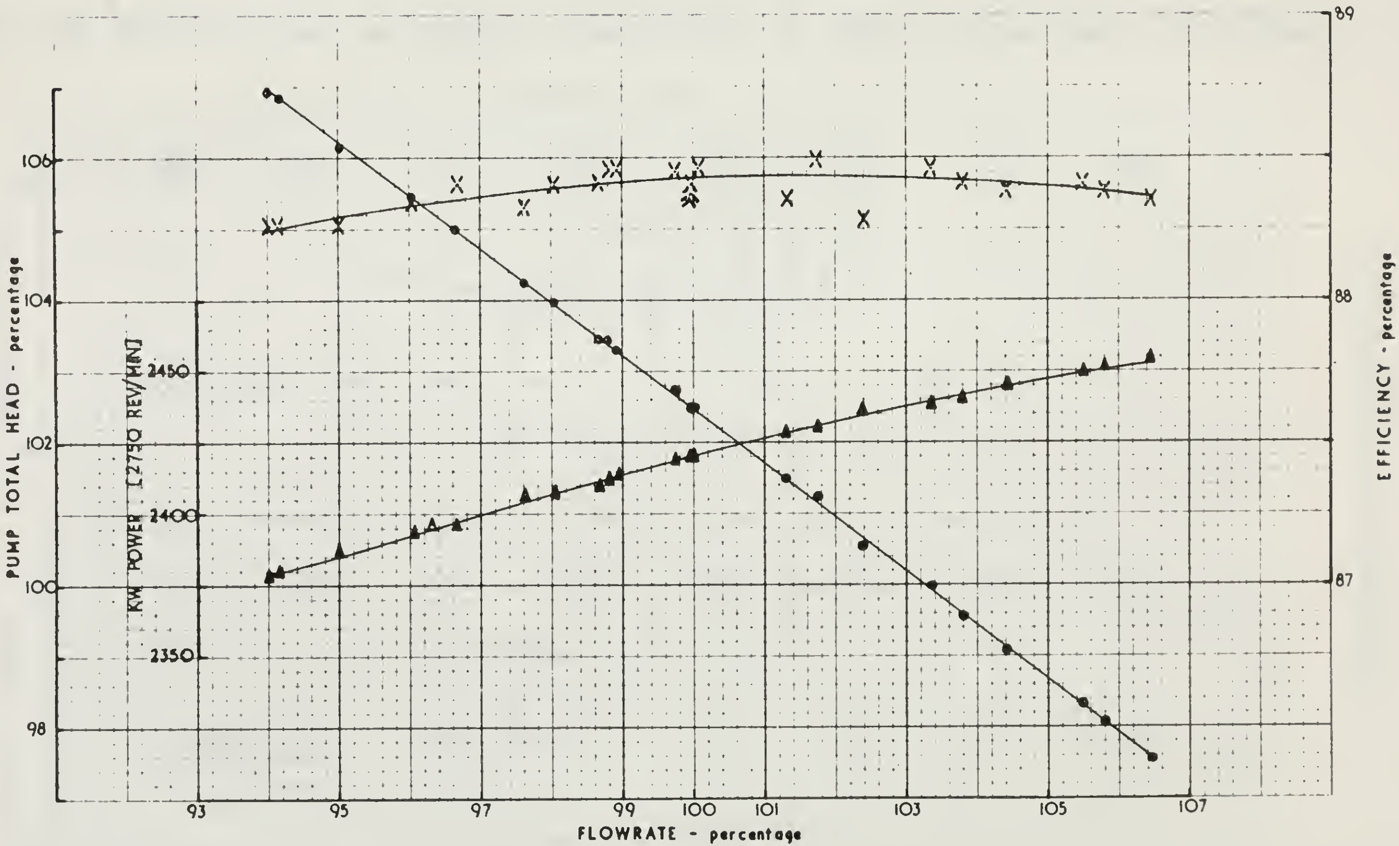


FIG.59 TEST SERIES 4a CHARACTERISTICS OF MODEL AT 2750 REV/MIN
ESCHER WYSS PUMP

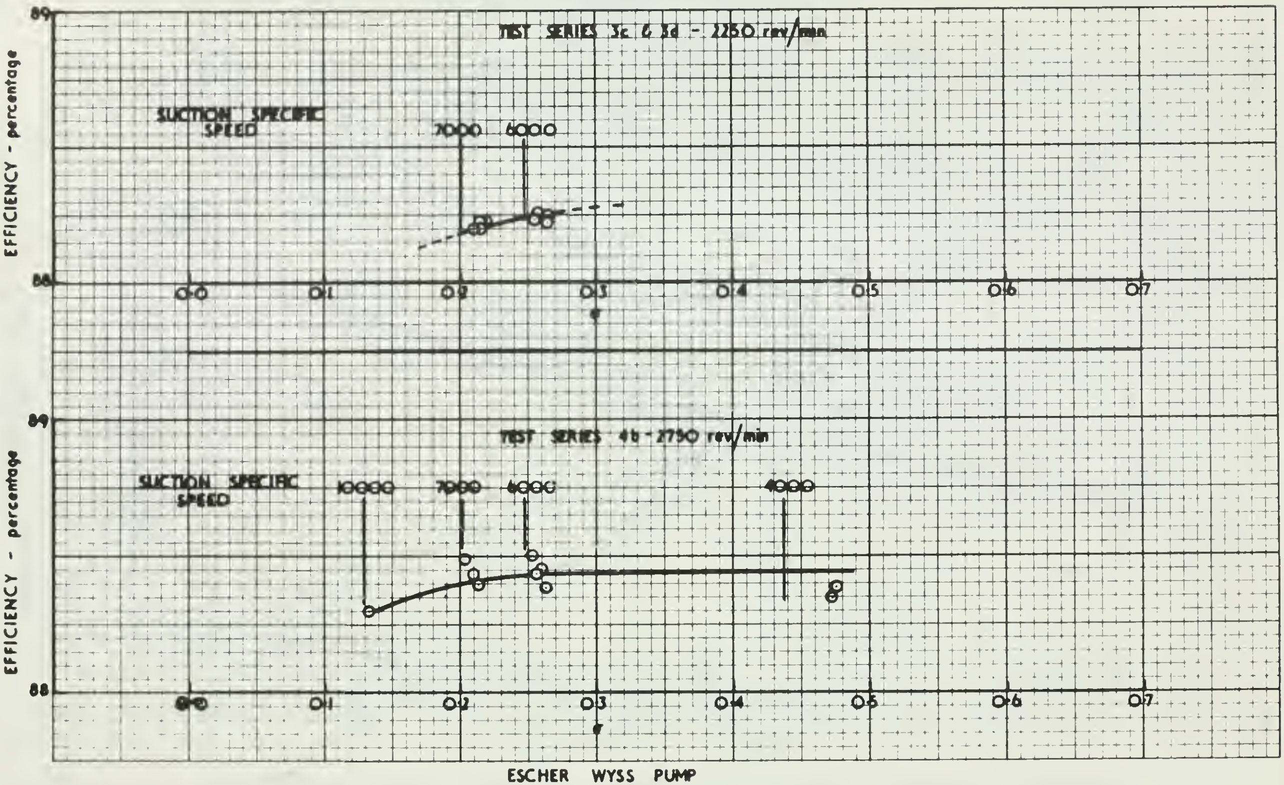


FIG 60 TEST SERIES 3c, 3d AND 4b CAVITATION CHARACTERISTICS OF MODEL AT 2250 AND 2750 REV/MIN

Figures 61 through 75 of the original report have been deleted for purposes of this publication. The information shown is considered proprietary by the pump manufacturer involved.

IV. CONTRACTS FOR FURNISHING AND INSTALLING THE VERTICAL CENTRIFUGAL PUMPS

STATE OF CALIFORNIA
THE RESOURCES AGENCY

DEPARTMENT OF WATER RESOURCES

NOTICE TO CONTRACTORS

Sealed bids for

FURNISHING AND INSTALLING
SEVEN VERTICAL CENTRIFUGAL PUMPS
FOR
TEHACHAPI PUMPING PLANT
STATE WATER FACILITIES
CALIFORNIA AQUEDUCT
TEHACHAPI DIVISION
KERN COUNTY, CALIFORNIA
SPECIFICATION NO. 67-24

will be received by the Department of Water Resources at the office of the Director of Water Resources, Room 1123, Resources Building, 1416 Ninth Street, Sacramento, California, until 10:00 a.m. on **Wednesday, September 27, 1967,** at which time they will be publicly opened and read at an announced location in the vicinity of such office.

Bids will be considered only if submitted for all of the work included in the above project. The work is defined in Section 1 of the Standard Provisions of the specifications and includes the following principal features:

Design, manufacture, shipment, delivery to the Tehachapi Pumping Plant, and installation of seven 315 cfs vertical shaft, four-stage centrifugal pumps complete with inlet transitions, casing discharge extensions, compensation joints, and auxiliary equipment. Installation will include the setting and aligning of the pumps and making connections to the pump discharge valves. The work also includes operational testing.

CONTRACTORS WHO BID ON THIS WORK SHALL BE PREQUALIFIED WITH THE DEPARTMENT FOR DESIGN AND MANUFACTURE OF THE SIZE AND TYPE OF PUMPS OUTLINED ABOVE.

Quantities of work, materials and equipment required for completion of the work are estimated to be as follows:

DEPARTMENT OF WATER RESOURCES ESTIMATE

PUMPS

Item 1	7	Each 4-stage centrifugal pump
Item 2		Completing model testing
~~Item 3~~	~~1,500~~	~~Square feet performing radiographic inspection~~
Item 4	1	Set tools, wrenches and devices
Item 5	35	Days services of erecting engineer
Item 6	100	Days liaison services

SPARE PARTS

Part Nos. refer to parts shown on Sheet No. 9, Drawing No. Q-3L5-1.

Item 7	1	Set babbitted liners for upper guide bearings (Part 5)
Item 8	1	Set babbitted liners for lower guide bearings (Part 41)
Item 9	1	Each upper shaft sleeve for main shaft where it passes through the packing box, including keys, screws, and other fastenings required for attaching the sleeve to the shaft (Part 24)
Item 10	1	Each lower shaft sleeve for main shaft where it passes through the packing box, including keys, screws, and other fastenings required for attaching the sleeve to the shaft (Part 36)
Item 11	1	Set upper shaft seal bushings (Part 25)
Item 12	1	Set lower shaft seal bushings (Part 37)

Item 13	1 Set four impeller wearing rings for all four stages (Part 32)
Item 14	1 Set four casing wearing rings for all four stages (Part 33)
Item 15	1 Set three interstage shaft sleeves (Part 30)
Item 16	1 Set three interstage bushings (Part 31)
Item 17	1 Pair balancing labyrinth (Parts 27 and 28)
Item 18	1 Lot spare nuts, bolts, gaskets, keys, pins and other miscellaneous components for one pump

The foregoing quantities are approximate only, being given as a basis for the comparison of bids, and the Department does not, expressly or by implication, agree that the quantities of work, materials and equipment actually required will correspond therewith.

WAGE RATES

In accordance with the provisions of Sections 1770 and 1773 of the California Labor Code, the Department has determined that the general prevailing rates of wages, including employer payments for health and welfare, pensions, vacations and similar purposes as provided in Section 1773.1 of the Labor Code, for the crafts, classifications, or types of workmen required for the work, in the locality of the work, are as follows:

Basic Rate Per Hour	Classification	Employer Payments For H and W	Vacation	Pension
	BUILDING CRAFTS			
$5.63	Electrician	.17 ph	None	.256 ph
4.785	Painter	.15 ph	.08 ph	.21 ph
6.02	Plumber	.43 ph	.40 ph	.30 ph
	CARPENTERS			
4.83	Carpenter	.23 phw/p	.15 phw/p	.30 phw/p
5.03	Millwright	.23 phw/p	.15 phw/p	.30 phw/p
	CEMENT MASONS			
4.60	Cement mason journeyman	.25 phw/p	.20 phw/p	.30 phw/p
	IRON WORKERS			
5.71	Ornamental iron worker	.28 phw	.18 phw	.20 phw
5.54	Reinforcing iron worker	Employer payments shown above are the same for all classifications of this group		
5.71	Structural iron worker			
	LABORERS			
3.91	Concrete saw man	.215 phw/p	.15 phw/p	.22 phw/p
3.99	Driller, jackhammer 2½ foot drill steel or longer			
3.70	Laborer general or construction	Employer payments shown above are the same for all classifications of this group		
3.825	Laborer—packing rod steel and pans			
3.91	Operator of pneumatic and electric tools			
3.04	Watchman			
	OPERATING ENGINEERS			
4.86	A-frame or winch truck operator	.30 phw/p	.30 phw/p	.30 phw/p
4.38	Air compressor, pump or generator operator			
5.26	Combination heavy-duty repairman and welder	Employer payments shown above are the same for all classifications of this group		
4.86	Elevator hoist operator			
4.38	Engineer—oiler and signalman			
5.16	Heavy-duty welder			
5.16	Machine tool operator			
4.86	Power concrete saw operator			
5.26	Universal equipment operator			
	TEAMSTERS			
	Trucks of legal payload capacity:			
4.51	15 tons to 20 tons	.30 phw/p	.15 phw/p	.20 phw/p
4.73	20 tons or more	Employer payments shown above are the same for all classifications of this group		
4.27	Warehouseman and teamster			

ph = per hour

php = per hour paid

phw = per hour worked

phw/p = per hour worked or paid

The general prevailing rate of wages for any craft, classification, or type of workmen required for the work but omitted above is determined to be not less than $3.04 per hour, plus employer payments for health and welfare, pensions, vacations and similar purposes, as provided in Section 1773.1 of the Labor Code and as determined from the collective bargaining agreement for such craft, classification, or type of workmen, in accordance with that Section.

Employer payments included in wages under Section 1773.1 of the Labor Code but not itemized above will be determined in accordance with that section from the collective bargaining agreements for the crafts, classifications, or types of workmen employed.

The general prevailing rate of wages for overtime, Sundays, and holidays for each craft, classification, or type of workmen required for the work, in the locality of the work, is determined to be not less than one and one-half ($1\frac{1}{2}$) times the basic hourly rate for the craft, classification, or type of workmen, as determined above.

Copies of all collective bargaining agreements relating to the work are on file and available for inspection in the office of the Department of Industrial Relations, Division of Labor Statistics and Research, San Francisco, California, as provided in the Labor Code.

Attention is directed to Section 3, Article (g), of the Standard Provisions providing for employment of apprentices on the work. The general prevailing rate of wages for apprentices is determined to be the standard wage paid to apprentices under the regulations of the trade at which he is employed. Information relative to employment of apprentices may be obtained from the Director of the Department of Industrial Relations, who is the Administrative Officer of the California Apprenticeship Council.

BIDDING

This notice, forms of bid and contract, and drawings and specifications for the work, hereinafter called bid documents, may be obtained at the office of the Department of Water Resources, Room 406-2, Resources Building, 1416 Ninth Street, Sacramento, California, or by mail upon written request to the Department of Water Resources, P. O. Box 388, Sacramento, California 95802. They may be seen at the above location or at the offices of the Department at Glen Drive, Oroville, California; 909 South Broadway, Los Angeles, California; 233 Junction Avenue, Livermore, California; 770 Motel Drive, Merced, California; 101 North Third Street, Patterson, California; 601 California Avenue, Bakersfield, California; 12885 Foothill Boulevard, San Fernando, California; and 2225 E. Avenue Q, Palmdale, California.

A CHARGE OF $5.00, WHICH IS NOT REFUNDABLE, WILL BE MADE FOR EACH SET OF REDUCED DRAWINGS AND SPECIFICATIONS.

Bid documents furnished to bidders not meeting prequalification or joint venture bidding requirements, or to prospective subcontractors, suppliers, or other parties not interested in bidding on the work, shall not be used for bidding purposes and will be so stamped.

All bidders shall be prequalified by the Department, in accordance with the State Contract Act and bid form requirements. Bid documents to be used in bidding will be furnished only to prequalified bidders, and will be furnished to joint venture bidders only if they meet the joint venture bidding requirements set forth in the bid form.

All bidders shall be licensed for the work when and as required by the provisions of Chapter 9 of Division 3 of the California Business and Professions Code.

Questions relating to bidding may be directed to the Office Engineer of the Department of Water Resources in Sacramento, at the location or address given above, or at Telephone 445-5018. A conducted tour of the site of the work will be scheduled for all interested prospective bidders.

The Director of Water Resources may reject any or all bids.

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES

WILLIAM R. GIANELLI
Director of Water Resources

Dated: April 7, 1967.

SPECIAL PROVISIONS

SECTION 10. GENERAL DESCRIPTION AND LOCATION OF THE WORK

(a) Description of the Work.—The work is defined in Section 1 and includes the design and manufacture, shipment, delivery to the Tehachapi Pumping Plant, and installation of seven 315 cfs vertical shaft, four-stage centrifugal pumps complete with inlet transitions, casing discharge extensions, compensation joints, and auxiliary equipment. Installation will include the setting and aligning of the pumps and making connections to the pump discharge valves. The work also includes operational testing. Anchor bolts and similar parts to be embedded will be installed in the pumping plant structure by others.

The Department will furnish at the site the main bridge crane service, electric power, erection space, water, and motors for installing and testing the pumps.

(b) Location of the Work.—The Tehachapi Pumping Plant site is located approximately 29 miles south of Bakersfield, California, in Kern County. Bakersfield is located on U.S. Highway 99 with rail service provided by the Southern Pacific Company and the Atchison, Topeka and Santa Fe. Highway access to the pumping plant is from Highway U.S. 99, approximately 6 miles along the Tehachapi Pumping Plant Road.

The Tehachapi Pumping Plant is a "U" shaped indoor type structure designed to house fourteen 315 cfs pumps. Installation of the pumps will be staged. This contract will include the initial seven pumps.

(c) Submission of Bids.—The Department will use model efficiency in determining the lowest responsible bidder pursuant to Article (i) of the Bidding Requirements and Conditions, and Section 11, Article (b). Each bidder shall have built and tested a complete four-stage model pump, which shall have been submitted for comparative testing at the National Engineering Laboratory, Ministry of Technology, East Kilbride, Glasgow, Scotland, prior to the time established in the Notice to Contractors for receiving bids. The model efficiency measured at the National Engineering Laboratory and stepped up using the "DMJM" step-up formula, will be the comparative prototype efficiency used in determining the lowest responsible bidder as prescribed in Section 11, Article (b). All model work shall be complete and the model efficiency value determined prior to the time for receiving bids given in the Notice to Contractors.

The Department has contracted with the firm of Daniel, Mann, Johnson and Mendenhall (DMJM), Los Angeles, California, to direct the model work, including preparation of model specifications, negotiation of model contracts, witnessing model tests and submitting the efficiency values. DMJM is also responsible for developing procedures for the confidential treatment of test data and of test results.

DMJM will submit the bidders' efficiency values to the Department in sealed envelopes at the time for receiving bids given in the Notice to Contractors. Immediately following the public opening and reading of the bids, bidders' efficiency values will be publicly opened and read. The bidders' efficiency value will be considered a part of the bid document, notwithstanding its separate submission and opening.

SECTION 11. SPECIAL CONDITIONS

(a) Time of Completion and Liquidated Damages.—Pursuant to the provisions of Section 5, Article (c), and Section 11, Article (b), the Contractor shall:

1. Complete the delivery of all pump foundation anchor bolts, embedded parts, and templates for installation by others, on or before

MAY 9, 1968

2. Install pumps and clear area to permit installation of motors by others, on or before

Pump No. E1	October 9, 1970
Pump No. E3	January 8, 1971
Pump No. E5	April 9, 1971
Pump No. E7	June 11, 1971
Pump No. E9	August 6, 1971
Pump No. E11	October 8, 1971
Pump No. E13	December 10, 1971

3. Complete field installation of pumps and auxiliary equipment as specified in Section 18, Article (b), on or before

Pump No. E1	December 18, 1970
Pump No. E3	March 19, 1971
Pump No. E5	June 18, 1971
Pump No. E7	August 20, 1971
Pump No. E9	October 22, 1971
Pump No. E11	December 24, 1971
Pump No. E13	February 25, 1972

4. Complete the balance of the work on or before June 1, 1972.

Should notice to begin the work be received later than November 10, 1967, the dates listed in Subparagraphs Nos. 1, 2, 3, and 4, will be extended by the number of days delay in receipt of notice to begin the work after that date.

Liquidated damages for failure to complete the portion of the work described in Subparagraph 1 within the time specified shall be $1,000 per day.

Liquidated damages for failure to complete the portion of the work described in Subparagraph 2 for any pump within the time specified shall be $300 per day per pump.

Liquidated damages for failure to complete the portion of the work described in Subparagraph 3 for any pump within the time specified shall be $300 per day per pump.

Liquidated damages for failure to complete the balance of the work within the time specified shall be $500 per day.

The maximum sum per day for liquidated damages for which the Contractor will be liable will be $2,600.

The pump pit for each pump will be available for the Contractor's use by the following date:

Pump No. E1------	June 26, 1970
Pump No. E3------	September 25, 1970
Pump No. E5------	December 25, 1970
Pump No. E7------	February 26, 1971
Pump No. E9------	April 23, 1971
Pump No. E11-----	June 25, 1971
Pump No. E13-----	August 27, 1971

If the Department fails to make the pump pit available for the Contractor's use by the date set forth above, such failure shall be considered a failure to furnish completed facilities of related projects within the meaning of Section 5, Article (d).

(b) Award of Contract.—In determining the lowest responsible bidder pursuant to Article (i) of the Bidding Requirements and Conditions, the Department will evaluate bids according to comparative prototype efficiencies furnished to the Department as described in Section 10. Award of contract, if made, will be to the responsible bidder having the lowest evaluated bid. The evaluated bid will consist of the total price bid plus any additions made pursuant to this article.

A "dead band" allowance of 0.2 percent will be applied to each bidder's comparative prototype efficiency to allow for scatter and inaccuracy in the comparative model testing. Efficiencies in the "dead band" will be considered equal for purposes of evaluation, and each efficiency more than 0.2 below the highest comparative prototype efficiency will be evaluated on its departure (evaluated difference) from the "dead band".

The following example illustrates this procedure:

Bidder	A	B	C
Comparative Prototype Efficiency (percent)	91.4	91.7	91.9
Departure from highest comparative prototype efficiency (percent)	0.5	0.2	0
Departure from "dead band" or "evaluated difference" (percent)	0.3	0	0

For bid evaluation purposes, ~~$210,000~~ $154,000 will be added to the bidder's total price for each 0.1 percent of "Evaluated Difference".

(c) Drawings.—The work shall conform to the following drawings. The drawings are not to be considered as defining the design details of the equipment to be furnished.

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
DIVISION OF DESIGN AND CONSTRUCTION
STATE WATER FACILITIES
CALIFORNIA AQUEDUCT
TEHACHAPI DIVISION
TEHACHAPI PUMPING PLANT
VERTICAL 4-STAGE CENTRIFUGAL PUMPS

Sheet No.	Drawing No.	Revision No.	Title
1	Q-3K1-1	1	Title Sheet
2	Q-3K2-1	1	Site Plan
3	Q-3L1-1	1	Pumping Plant—Elevation 1178.00—Plan
4	Q-3L1-2	1	Pumping Plant—Elevation 1192.00—Plan
5	Q-3L1-3	1	Pumping Plant—Elevation 1210.00—Plan
6	Q-3L2-1	1	Pumping Plant—Longitudinal Section
7	Q-3L3-1	1	Pumping Plant—Transverse Section
8	Q-3L4-1	1	Pump Inlet Neat Lines
9	Q-3L5-1	1	Pump Schematic Cross Section
10	Q-3L6-1		Crane Clearance Diagram
11	T-0E1-2		Format for CPM Type Contractor's Schedule

(d) Definitions.—The definitions of drawings and Engineer, given in Section 1, are replaced by the following:

ABSTRACT OF BIDS
Furnishing and Installing 7 Vertical Centrifugal Pumps
Specification No. 67-24

Item No.	Description	Quantity	Unit	DWR Engineer's Estimate	Baldwin-Lima-Hamilton Corp.	Allis-Chalmers Mfg. Co.	Newport News Shipbuilding and Dry Dock Co.
1	4-stage centrifugal pump	7	Each	$13,685,000.00	$11,562,565.00	$12,829,411.00	$13,761,300.00
2	Completing model testing	LUMP SUM	LUMP SUM	50,000.00	51,480.00	70,000.00	40,000.00
3	DELETED						
4	Tools, wrenches and devices	1	Set	10,000.00	27,600.00	350,000.00	52,500.00
5	Services of erecting engineer	35	Days	4,375.00	3,675.00	4,200.00	4,725.00
6	Liaison services	100	Days	12,500.00	15,000.00	15,000.00	14,000.00
	SPARE PARTS						
7	Babbitted liners for upper guide bearings (Part 5)	1	Set	4,780.00	2,400.00	4,100.00	6,200.00
8	Babbitted liners for lower guide bearings (Part 41)	1	Set	4,780.00	1,600.00	4,100.00	3,000.00
9	Upper shaft sleeve for main shaft where it passes through the packing box, including keys, screws, and other fastenings required for attaching the sleeve to the shaft (Part 24)	1	Each	2,000.00	3,100.00	1,800.00	2,450.00
10	Lower shaft sleeve for main shaft where it passes through the packing box, including keys, screws, and other fastenings required for attaching the sleeve to the shaft (Part 36)	1	Each	2,000.00	2,100.00	2,050.00	1,650.00
11	Upper shaft seal bushings (Part 25)	1	Set	800.00	3,200.00	5,100.00	2,300.00
12	Lower shaft seal bushings (Part 37)	1	Set	800.00	2,300.00	5,100.00	1,190.00
13	Four impeller wearing rings for all four stages (Part 32)	1	Set	18,000.00	10,500.00	9,800.00	14,500.00
14	Four casing wearing rings for all four stages (Part 33)	1	Set	26,000.00	10,500.00	24,500.00	11,000.00
15	Three interstage shaft sleeves (Part 30)	1	Set	10,000.00	9,600.00	11,000.00	10,150.00
16	Three interstage bushings (Part 31)	1	Set	3,000.00	8,000.00	8,200.00	7,400.00
17	Balancing labyrinth (Parts 27 and 28)	1	Pair	20,000.00	14,000.00	26,000.00	15,400.00
18	Spare nuts, bolts, gaskets, keys, pins and other miscellaneous components for one pump	1	Lot	3,000.00	10,000.00	16,400.00	4,030.00
	TOTAL			$13,857,035.00	$11,737,620.00	$13,386,761.00	$13,951,795.00

EVALUATION OF BIDS

SEVEN VERTICAL CENTRIFUGAL PUMPS FOR

TEHACHAPI PUMPING PLANT--SPEC. NO. 67-24

		ALLIS CHALMERS/ SULZER BROS.	BALDWIN-LIMA-HAMILTON/ J. M. VOITH	NEWPORT NEWS SB&DDCO/ ESCHER WYSS
(1)	Comparative Prototype Efficiency (percent)	92.4	92.2	91.3
(2)	Departure from highest comparative prototype efficiency (percent)	---	0.2	1.1
(3)	Departure from 0.2% "dead band" or "evaluated difference" (percent)	---	---	0.9
(4)	$154,000 times each 0.1 percent given in line (3)	---	---	$1,386,000
(5)	BID (Total from Abstract of Bids)	$13,386,761	$11,737,620	$13,951,795
(6)	EVALUATED BID (line (4) + line (5))	$13,386,761	$11,737,620	$15,337,795
			LOW BIDDER AND CONTRACTOR	

STATE OF CALIFORNIA

THE RESOURCES AGENCY

DEPARTMENT OF WATER RESOURCES

CONTRACT FOR

FURNISHING AND INSTALLING
SEVEN VERTICAL CENTRIFUGAL PUMPS
FOR
TEHACHAPI PUMPING PLANT
STATE WATER FACILITIES
CALIFORNIA AQUEDUCT
TEHACHAPI DIVISION
KERN COUNTY, CALIFORNIA
SPECIFICATION NO. 67-24

CONTRACT NO. 356081

THIS CONTRACT, made in duplicate this 5th day of October, 1967, in accordance with the provisions of the State Contract Act and other applicable laws of the State of California, between the State of California, acting by and through its Department of Water Resources, hereinafter called the Department, and

Baldwin-Lima-Hamilton Corporation

hereinafter called the Contractor;

WITNESSETH, That the Department and the Contractor mutually agree as follows:

ARTICLE I.—This contract includes and incorporates by this reference the notice to contractors and Contractor's bid for the above named project, the contract bonds furnished by the Contractor pursuant to his bid and attached hereto, the drawings and specifications for such project, all addenda to the above documents, and all authorized changes therein. All definitions stated in the Standard Provisions of the specifications shall apply herein.

ARTICLE II.—The Contractor shall provide and furnish except as otherwise expressly provided in the specifications, all materials, equipment, labor, methods, processes, construction materials and equipment, tools, plants, supplies, power, water, transportation and other things necessary to complete in a good and workmanlike manner, in accordance with the drawings, specifications and all other parts of this contract, and to the satisfaction of the Engineer, all of the facilities specified, indicated, shown, or contemplated by the drawings, specifications and other parts of this contract as comprising and necessary for completion of the above named project, and shall perform all other obligations imposed upon him by this contract.

ARTICLE III.—The Department shall pay to the Contractor, and the Contractor shall accept, as full compensation for performance of his obligations under ARTICLE II and for all risks and liabilities in connection therewith, the prices set forth in the Contractor's bid, all in accordance with and subject to the express terms and conditions of the specifications, the Contractor's bid, and other parts of this contract, and the Department shall perform all other obligations imposed upon it by this contract.

ARTICLE IV.—This contract shall apply to and bind the successors and assigns of the parties hereto.

IN WITNESS WHEREOF, the parties hereto have executed this contract as of the 5TH day of OCTOBER, 1967.

STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES

William R. Gianelli
WILLIAM R. GIANELLI
Director of Water Resources

BALDWIN - LIMA - HAMILTON CORPORATION
PHILADELPHIA 42, PA.

By

Contractor

By E. H. Schoonmaker
E. H. SCHOONMAKER
MANAGER - MARKETING
Title

APPROVED:

Alfred R. Golzé
Deputy Director,
State Water Project

Donald A. Sanders
As To Funds

P. A. Towner
As To Legal Form and Sufficiency

I hereby certify that I have examined the within contract and find the same to be in accordance with the provisions of the State Contract Act.

THOMAS C. LYNCH
Attorney General of the State of California

By August J. Gruenke
Deputy Attorney General

Dated October 25, 1967.

STATE OF CALIFORNIA

THE RESOURCES AGENCY

DEPARTMENT OF WATER RESOURCES

NOTICE TO CONTRACTORS

Sealed bids for

FURNISHING AND INSTALLING
FOUR VERTICAL CENTRIFUGAL PUMPS
FOR
TEHACHAPI PUMPING PLANT
STATE WATER FACILITIES
CALIFORNIA AQUEDUCT
TEHACHAPI DIVISION
KERN COUNTY, CALIFORNIA
SPECIFICATION NO. 67-56

will be received by the Department of Water Resources at the office of the Director of Water Resources, Room 1115, Resources Building, 1416 Ninth Street, Sacramento, California, until 10:00 a.m. on **Wednesday, October 18, 1967**, at which time they will be publicly opened and read at an announced location in the vicinity of such office.

Bids will be considered only if submitted for all of the work included in the above project. The work is defined in Section 1 of the Standard Provisions of the specifications and includes the following principal features:

> Designing, manufacturing, delivering, installing, and testing four 315 cfs vertical shaft, four-stage centrifugal pumps for the Tehachapi Pumping Plant, complete with inlet transitions, casing discharge extensions, compensation joints, and auxiliary equipment; and furnishing and delivering three extra sets of foundation anchor bolts and similar parts to be embedded for 315 cfs four-stage centrifugal pumps.

CONTRACTORS WHO BID ON THIS WORK SHALL BE PREQUALIFIED WITH THE DEPARTMENT FOR DESIGN AND MANUFACTURE OF THE SIZE AND TYPE OF PUMPS OUTLINED ABOVE.

Quantities of work, materials and equipment required for completion of the work are estimated to be as follows:

DEPARTMENT OF WATER RESOURCES ESTIMATE

PUMPS

Item 1	4	Each 4-stage centrifugal pump
Item 2		Completing model testing
Item 3	1	Set tools, wrenches and devices
Item 4	35	Days services of erecting engineer
Item 5	100	Days liaison services

SPARE PARTS

Part Nos. refer to parts shown on Sheet No. 9, Drawing No. Q-3L21-1

Item 6	1	Set babbitted liners for upper guide bearings (Part 5)
Item 7	1	Set babbitted liners for lower guide bearings (Part 41)
Item 8	1	Each upper shaft sleeve for main shaft where it passes through the packing box, including keys, screws, and other fastenings required for attaching the sleeve to the shaft (Part 24)

Item 9	1 Each lower shaft sleeve for main shaft where it passes through the packing box, including keys, screws, and other fastenings required for attaching the sleeve to the shaft (Part 36)
Item 10	1 Set upper shaft seal bushings (Part 25)
Item 11	1 Set lower shaft seal bushings (Part 37)
Item 12	1 Set four impeller wearing rings for all four stages (Part 32)
Item 13	1 Set four casing wearing rings for all four stages (Part 33)
Item 14	1 Set three interstage shaft sleeves (Part 30)
Item 15	1 Set three interstage bushings (Part 31)
Item 16	1 Pair balancing labyrinth (Parts 27 and 28)
Item 17	1 Lot spare nuts, bolts, gaskets, keys, pins and other miscellaneous components for one pump

The foregoing quantities are approximate only, being given as a basis for the comparison of bids, and the Department does not, expressly or by implication, agree that the quantities of work, materials and equipment actually required will correspond therewith.

WAGE RATES

In accordance with the provisions of Sections 1770 and 1773 of the California Labor Code, the Department has determined that the general prevailing rates of wages, including employer payments for health and welfare, pensions, vacations and similar purposes as provided in Section 1773.1 of the Labor Code, for the crafts, classifications, or types of workmen required for the work, in the locality of the work, are as follows:

Classification	Straight Time	Overtime	Saturday	Sunday	Holiday
BUILDING CRAFTS					
Electrician	$6.308	$12.247	*	*	*
Painter	5.205	7.597	*	*	*
Plumber	7.15	13.17	*	*	*
CARPENTERS					
Carpenter	5.80	10.89	*	*	*
Millwright	6.00	11.29	*	*	*
CEMENT MASONS					
Cement Mason Journeyman	5.64	8.06	$10.48	*	*
IRON WORKERS					
Ornamental Iron Worker	6.37	12.08	*	*	*
Reinforcing Iron Worker	6.20	11.74	*	*	*
Structural Iron Worker	6.37	12.08	*	*	*
LABORERS					
Laborer, General or Construction	4.535	6.46	*	$8.385	*
Laborer—Packing Rod Steel	4.66	6.647	*	8.635	*
Operator of Pneumatic and Electric Tools	4.745	6.775	*	8.805	*
Watchman	3.875	5.47	*	7.065	*
OPERATING ENGINEERS					
A-Frame or Winch Truck	6.06	8.565	*	11.07	16.08
Air Compressor, Pump or Generator	5.58	7.845	*	10.11	14.64
Engineer—Oiler and Signalman	5.58	7.845	*	10.11	14.64
Heavy-Duty Welder	6.36	9.015	*	11.67	16.98
Machine Tool Operator	6.36	9.015	*	11.67	16.98
Universal Equipment Operator	6.46	9.165	*	11.87	17.28
TEAMSTERS					
Trucks of Legal Payload Capacity:					
15 Tons to 20 Tons	5.46	7.79	*	10.12	*
20 Tons or More	5.68	8.12	*	10.56	*
Teamster	5.22	7.43	*	9.64	*

The general prevailing rate of wages for any craft, classification, or type of workmen required for the work but omitted above is determined to be not less than $3.875 per hour, plus employer payments for health and welfare, pensions, vacations and similar purposes, as provided in Section 1773.1 of the Labor Code and as determined from the collective bargaining agreement for such craft, classification, or type of workmen, in accordance with that section.

Employer payments included in wages under Section 1773.1 of the Labor Code but not itemized above will be determined in accordance with that section from the collective bargaining agreements for the crafts, classifications, or types of workmen employed.

The general prevailing rate of wages for overtime, Sundays, and holidays for each craft, classification, or type of workmen required for the work, in the locality of the work, is determined to be not less than one and one-half (1½) times the basic hourly rate for the craft, classification, or type of workmen, as determined above.

Copies of all collective bargaining agreements relating to the work are on file and available for inspection in the office of the Department of Industrial Relations, Division of Labor Statistics and Research, San Francisco, California, as provided in the Labor Code.

Attention is directed to Section 3, Article (g), of the Standard Provisions providing for employment of apprentices on the work. The general prevailing rate of wages for apprentices is determined to be the standard wage paid to apprentices under the regulations of the trade at which he is employed. Information relative to employment of apprentices may be obtained from the Director of the Department of Industrial Relations, who is the Administrative Officer of the California Apprenticeship Council.

BIDDING

This notice, forms of bid and contract, and drawings and specifications for the work, hereinafter called bid documents, may be obtained at the office of the Department of Water Resources, Room 406-2, Resources Building, 1416 Ninth Street, Sacramento, California, or by mail upon written request to the Department of Water Resources, P. O. Box 388, Sacramento, California 95802. They may be seen at the above location or at the offices of the Department at Glen Drive, Oroville, California; 909 South Broadway, Los Angeles, California; 233 Junction Avenue, Livermore, California; 101 North Third Street, Patterson, California; 601 California Avenue, Bakersfield, California; 12885 Foothill Boulevard, San Fernando, California; and 2225 E. Avenue Q, Palmdale, California.

A CHARGE OF $5.00, WHICH IS NOT REFUNDABLE, WILL BE MADE FOR EACH SET OF REDUCED DRAWINGS AND SPECIFICATIONS.

Bid documents furnished to bidders not meeting prequalification or joint venture bidding requirements, or to prospective subcontractors, suppliers, or other parties not interested in bidding on the work, shall not be used for bidding purposes and will be so stamped.

All bidders shall be prequalified by the Department, in accordance with the State Contract Act and bid form requirements. Bid documents to be used in bidding will be furnished only to prequalified bidders, and will be furnished to joint venture bidders only if they meet the joint venture bidding requirements set forth in the bid form.

All bidders shall be licensed for the work when and as required by the provisions of Chapter 9 of Division 3 of the California Business and Professions Code.

Questions relating to bidding may be directed to the Office Engineer of the Department of Water Resources in Sacramento, at the location or address given above, or at Telephone 445-5018.

The Director of Water Resources may reject any or all bids.

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES

WILLIAM R. GIANELLI
Director of Water Resources

Dated: September 1, 1967

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SPECIAL PROVISIONS

SECTION 10. GENERAL DESCRIPTION AND LOCATION OF THE WORK

(a) Description of the Work.—The work is defined in Section 1 and includes designing, manufacturing, delivering, installing, and testing four 315 cfs vertical shaft, four-stage centrifugal pumps for the Tehachapi Pumping Plant, complete with inlet transitions, casing discharge extensions, compensation joints, and auxiliary equipment; and furnishing and delivering three extra sets of foundation anchor bolts and similar parts to be embedded for 315 cfs four-stage centrifugal pumps.

Foundation anchor bolts and similar parts to be embedded will be installed in the pumping plant structure by others, however, the Contractor shall furnish templates for installing embedded parts and shall provide the services of an erecting engineer to give technical direction through the Engineer for installing embedded parts.

The Department will furnish 75-ton bridge crane service in the West Wing and erection space for installing the pumps; and motors, electric power and water for testing the pumps.

(b) Location of the Work.—The Tehachapi Pumping Plant is located approximately 29 miles south of Bakersfield, California, in Kern County. Bakersfield is located on U.S. Highway 99 with rail service provided by the Southern Pacific Company and the Atchison, Topeka and Santa Fe. Highway access to the pumping plant is from Highway U.S. 99, approximately 6 miles along the Tehachapi Pumping Plant Road.

The Tehachapi Pumping Plant is a "U" shaped indoor type structure designed to house fourteen 315 cfs pumps. Installation of the pumps will be staged. This contract will include four of the fourteen pumps.

(c) Submission of Bids.—The Department will use model efficiency in determining the lowest responsible bidder pursuant to Article (i) of the Bidding Requirements and Conditions, and Section 11, Article (i). Each bidder shall have built and tested a complete four-stage model pump, which shall have been submitted for comparative testing at the National Engineering Laboratory, Ministry of Technology, East Kilbride, Glasgow, Scotland, prior to the time established in the Notice to Contractors for receiving bids. The model efficiency measured at the National Engineering Laboratory and stepped up using the step-up formula given in Section 13, Article (c), will be the comparative prototype efficiency used in determining the lowest responsible bidder as prescribed in Section 11, Article (i). All model work shall be complete and the model efficiency value determined prior to the time for receiving bids given in the Notice to Contractors.

The Department has contracted with the firm of Daniel, Mann, Johnson and Mendenhall (DMJM), Los Angeles, California, to direct the model work, including preparation of model specifications, negotiation of model contracts, witnessing model tests and submitting the efficiency values.

DMJM will submit the bidders' efficiency values to the Department at the time for receiving bids given in the Notice to Contractors. Immediately following the public opening and reading of the bids, bidders' efficiency values will be publicly read. The bidders' efficiency value will be considered a part of the bid document, notwithstanding its separate submission.

SECTION 11. SPECIAL CONDITIONS

(a) Time of Completion and Liquidated Damages.—Pursuant to the provisions of Section 5, Article (c), and Section 11, Article (i), the Contractor shall:

1. Complete the delivery of all pump foundation anchor bolts, embedded parts, and templates pursuant to Section 16, Article (d), for installation by others, on or before

JUNE 1, 1968

2. Install pumps and clear area to permit installation of motors by others, on or before

Pump No. W2	October 9, 1970
Pump No. W4	January 8, 1971
Pump No. W6	April 9, 1971
Pump No. W8	June 11, 1971

3. Complete field installation of pumps and auxiliary equipment as specified in Section 18, Article (b), on or before

Pump No. W2	December 4, 1970
Pump No. W4	March 5, 1971
Pump No. W6	June 4, 1971
Pump No. W8	August 20, 1971

Should notice to begin the work be received later than December 1, 1967, the dates listed in Subparagraphs Nos. 1, 2, and 3, will be extended by the number of days delay in receipt of notice to begin the work after that date.

Liquidated damages for failure to complete the portion of the work described in Subparagraph 1 within the time specified shall be $1,000 per day.

Liquidated damages for failure to complete the portion of the work described in Subparagraph 2 for any pump within the time specified shall be $300 per day per pump.

Liquidated damages for failure to complete the portion of the work described in Subparagraph 3 for any pump within the time specified shall be $300 per day per pump.

The maximum sum per day for liquidated damages for which the Contractor will be liable will be $1,700.

The pump pit for each pump will be available for the Contractor's use by June 26, 1970.

If the Department fails to make the pump pit available for the Contractor's use by the date set forth above, such failure shall be considered a failure to furnish completed facilities of related projects within the meaning of Section 5, Article (d).

(b) Definitions.—The abbreviation of "ASA" given in Section 1 is replaced by the following:

ASA—A standard published by USAS.

The following abbreviation added to Section 1:

USAS—United States of America Standard Institute (formerly the American Standards Association).

The definitions of "Acceptance", "Drawings", and "Engineer", given in Section 1, are replaced by the following:

Acceptance—The formal written acceptance of the work by the Director or his properly authorized representative.

Drawings—All drawings listed in the Special Provisions and any addenda thereto, all supplemental drawings and revised drawings furnished by the Engineer, and exact reproductions of any of the foregoing.

Engineer—The Department's Deputy Director, acting either directly or through properly authorized representatives, each representative acting within the scope of his delegated authority.

The following definition is added to Section 1:

Deputy Director—The Department's Deputy Director, State Water Project.

Wherever the term "Chief Engineer" appears in the contract, it shall be replaced with the term "Deputy Director".

(c) Fair Employment Practices.—In Section 3, Article (c), delete the opening statement and replace it with the following:

In connection with the performance of the work under this contract within the State of California, the Contractor agrees as follows:

Delete the second paragraph of Section 3, Article (c)(4), and replace it with the following:

The awarding authority shall deem a finding of willful violation of the Fair Employment Practices Act to have occurred upon receipt of written notice from the Fair Employment Practices Commission that it has investigated and determined that the Contractor has violated the Fair Employment Practices Act and has issued an order under Labor Code Section 1426 or obtained an injunction under Labor Code Section 1429.

(d) Time Extensions.—In Section 5, Article (d), add at the end of paragraph (8):

Priority rating of orders or materials by the Federal Government for national defense purposes will be considered for time extension purposes on the same basis and subject to the same conditions, including unforeseeability, as any other governmental act, unless the Engineer is specifically directed otherwise by judicial authority or administrative authority of the Federal Government. A priority rating on work being performed by the Contractor or a subcontractor or supplier will be considered unforeseeable only if the rating was placed on the work following award of this contract, unless the Engineer is specifically directed otherwise by judicial authority or administrative authority of the Federal Government.

(e) Authority for Changes.—In Section 7, Article (b), add at the end of the first paragraph:

He may also order the elimination of a portion of the work even though required for its proper completion if, due to unforeseen causes, the Contractor would be unduly delayed in performing that portion of the work or his performance thereof would otherwise be adverse to the Department's interests, and if its elimination will not change the general scope and purpose of the project.

(f) Reductions in the Work.—In Section 7, Article (f), revise the first sentence of the second paragraph to read as follows:

Subject to succeeding provisions of this article, the Contractor will be paid those actual necessary costs of any portion of the work eliminated by an order for changes which were incurred prior to such order, with such allowance for superintendence, general expense and profit as may be reasonably allocated to such costs by the Contractor and approved by the Engineer.

(g) Force Account Payment.—In Section 9, Article (c), delete Subarticle (1), and replace it with the following:

(1) General.—Force account payment will be made only in accordance with Section 7, "Changes and Changed Conditions", and will be determined separately for each change. Portions of the work to be paid for on a force account basis are hereinafter called force account work.

When force account work is performed by a subcontractor or other force not within the Contractor's organization, the Contractor shall agree with that party as to the distribution of the payment made for such work, and no additional payment will be made by reason of its performance by such party.

Force account payment for any change will consist of the actual necessary costs of labor, materials, and equipment, and construction equipment used in the force account work as determined by the Engineer in accordance with Subarticles (3), (4), and (5), respectively of Section 9, Article (c), plus an allowance on such costs for superintendence, general expense and profit determined in accordance with the following schedule, which allowance shall constitute full compensation for all costs of such work not expressly included as actual necessary costs under Subarticles (3), (4), and (5), of Section 9, Article (c).

Total Increment of Actual Necessary Costs of Labor, Materials and Equipment, and Construction Equipment	Allowance for Superintendence, General Expense, and Profit —In Percent	
	On Costs of Labor	On Costs of Materials and Equipment and Construction Equipment
$0 to $25,000	20%	17%
$25,000 to $50,000	19%	16%
$50,000 to $100,000	18%	15%
$100,000 to $150,000	17%	14%
$150,000 to $200,000	16%	13%
$200,000 to $300,000	15%	12%
$300,000 to $400,000	14%	11%
Over $400,000	13%	10%

The allowance will be computed for each increment of actual necessary costs by applying to the respective components of that increment the respective percentage shown opposite that increment, and totaling the results obtained. The percentage rates of allowance on any cost increment shall not be affected by the amount of subsequent cost increments. Thus, if the actual necessary costs of the force account work totals $120,000, the total allowance thereon will be computed as follows:

20% of the labor component of the first increment ($25,000) ; plus

19% of the labor component of the second increment ($25,000) ; plus

18% of the labor component of the third increment ($50,000) ; plus

17% of the labor component of the fourth increment ($20,000) ; plus

17% of the M&E&CE* component of the first increment; plus

16% of the M&E&CE component of the second increment; plus

15% of the M&E&CE component of the third increment; plus

14% of the M&E&CE component of the fourth increment.

* Materials & Equipment & Construction Equipment.

(h) Progress Payments.—In Section 9, Article (d), delete Subarticle (4), and replace it with the following:

(4) General Conditions.—No progress estimate or payment need be made when, in the judgment of the Engineer, there may be cause for termination of the contract under Section 5, Article (h), or when, in his judgment, the total value of work done and materials and equipment furnished since the last estimate is less than $300.

The Engineer may withhold all or any part of a progress payment otherwise payable upon the Contractor's failure to submit any schedule for the work, whether preliminary or detailed in nature, in the manner and within the time specified in the Special Provisions. Progress payments or portions thereof so withheld may, at the discretion of the Engineer, be paid to the Contractor following compliance with the schedule submission requirements.

No progress estimate or payment shall be considered an approval or acceptance of any work, materials, or equipment. All such estimates and payments shall be subject to correction in the final estimate.

The Contractor shall not be entitled to interest on any progress payment or portion thereof which is withheld pending the issuance of a change order or claim decision, withheld due to an error in the progress estimate, or withheld pursuant to any provision of the contract.

(i) Award of Contract.—In determining the lowest responsible bidder pursuant to Article (i) of the Bidding Requirements and Conditions, the Department will evaluate bids according to comparative prototype efficiencies furnished to the Department as described in Section 10. Award of contract, if made, will be to the responsible bidder having the lowest evaluated bid. The evaluated bid will consist of the total price bid plus any additions made pursuant to this article.

A "dead band" allowance of 0.2 percent will be applied to each bidder's comparative prototype efficiency to allow for scatter and inaccuracy in the comparative model testing. Efficiencies in the "dead band" will be considered equal for purposes of evaluation, and each efficiency more than 0.2 below the highest comparative prototype efficiency will be evaluated on its departure (evaluated difference) from the "dead band".

The following example illustrates this procedure:

Bidder	A	B	C
Comparative Prototype Efficiency (percent)	91.4	91.7	91.9
Departure from highest comparative prototype efficiency (percent)	0.5	0.2	0
Departure from "dead band" or "evaluated difference" (percent)	0.3	0	0

For bid evaluation purposes, $88,000 will be added to the bidder's total price for each 0.1 percent of "Evaluated Difference".

(j) Drawings.—The work shall conform to the following drawings. The drawings are not to be considered as defining the design details of the equipment to be furnished.

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
DIVISION OF DESIGN AND CONSTRUCTION
STATE WATER FACILITIES
CALIFORNIA AQUEDUCT
TEHACHAPI DIVISION
TEHACHAPI PUMPING PLANT
VERTICAL 4-STAGE CENTRIFUGAL PUMPS

Sheet No.	Drawing No.	Title
1	Q-3K10-1	Title Sheet
2	Q-3K11-1	Site Plan

Sheet No.	Drawing No.	Title
3	Q-3L17-1	Pumping Plant—Elev. 1178.00—Plan
4	Q-3L17-2	Pumping Plant—Elev. 1192.00—Plan
5	Q-3L17-3	Pumping Plant—Elev. 1210.00—Plan
6	Q-3L18-1	Pumping Plant—Longitudinal Section
7	Q-3L19-1	Pumping Plant—Transverse Section
8	Q-3L20-1	Pump Inlet Neat Lines
9	Q-3L21-1	Pump Schematic Cross Section
10	Q-3L22-1	Crane Clearance Diagram
11	T-OE1-2	Format for CPM Type Contractor's Schedule

(k) Facilities and Services to be Furnished by the Department.—The Department will furnish without cost to the Contractor, the following:

1. All items necessary for operational testing of the pumps as specified in Section 18, Article (c).

2. Temporary storage areas and erection areas in the pumping plant.

3. Crane services. The crane will have the characteristics and limits shown on the drawings.

Attention is directed to Section 11, Article (l). The Contractor shall cooperate with the Engineer and other contractors in the use of the storage and erection space available in the pumping plant. Notwithstanding any provisions of Section 5, Articles (d) and (e) to the contrary, the Contractor shall not be entitled to additional compensation or time under the contract for damage or delay to the work caused by the limited storage and erection space available in the pumping plant or the operations of other contractors therein.

Use of the crane will be subject to approval of the Engineer, who will allocate crane time on a reasonable basis among the contractors working in the area. Crane service will be available on a three-shift basis. The Contractor shall submit at regular intervals, not exceeding one week, a preliminary time schedule of his crane requirements for the next succeeding time period. A final schedule shall be submitted by the Contractor at least three days prior to the next succeeding time period. The Engineer will review the schedule and allot crane time to the Contractor.

Notwithstanding any provisions of Section 5, Articles (d), and (e), to the contrary, the Contractor shall not be entitled to additional compensation or time under the contract for damage or delay to the work caused by such allocation of crane time by the Engineer. Crane operators will be employed by others, but the Contractor shall supervise the operators during the periods that the cranes are assigned to his work. The Contractor shall furnish signal men and riggers for lifts made for him. The Contractor shall be responsible under Section 4, Articles (b), (c), and (d), for any injury or damage resulting from crane operation under his supervision to the same extent as though the crane operator were his employee.

(l) Cooperation with Other Contractors.—In addition to complying with the provisions of Section 4, Article (f), the Contractor shall exchange with the contractors for the motors, discharge valves, and crane, all necessary drawings, dimensions, templates, gages, and other information required to ensure complete and proper design and manufacture of all connections or related parts of the pumps, motors, valves and crane. Two copies of all drawings and all correspondence relating to drawings and specifications interchanged between contractors shall be furnished to the Department.

ABSTRACT OF BIDS
Furnishing and Installing 4 Vertical Centrifugal Pumps
Specification No. 67-56

Item No.	Description	Quantity	Unit	DWR Engineer's Estimate	Allis-Chalmers Mfg. Co.	Baldwin-Lima-Hamilton Corp.	Newport News Shipbuilding and Dry Dock Co.
1	4-stage centrifugal pump	4	Each	$6,969,200.00	$6,138,748.00	$6,639,132.00	$7,531,260.00
2	Completing model testing	LUMP SUM	LUMP SUM	51,480.00	52,000.00	44,000.00	40,000.00
3	Tools, wrenches and devices	1	Set	27,600.00	30,000.00	27,600.00	50,000.00
4	Services of erecting engineer	35	Days	3,675.00	4,200.00	3,675.00	4,725.00
5	Liaison services	100	Days	15,000.00	15,000.00	15,000.00	14,000.00
	SPARE PARTS						
6	Babbitted liners for upper guide bearings (Part 5)	1	Set	2,400.00	4,100.00	2,400.00	6,200.00
7	Babbitted liners for lower guide bearings (Part 41)	1	Set	1,600.00	4,100.00	1,600.00	3,000.00
8	Upper shaft sleeve for main shaft where it passes through the packing box, including keys, screws, and other fastenings required for attaching the sleeve to the shaft (Part 24)	1	Each	3,100.00	1,800.00	3,100.00	2,400.00
9	Lower shaft sleeve for main shaft where it passes through the packing box, including keys, screws, and other fastenings required for attaching the sleeve to the shaft (Part 36)	1	Each	2,100.00	2,050.00	2,100.00	1,650.00
10	Upper shaft seal bushings (Part 25)	1	Set	3,200.00	4,000.00	3,200.00	2,300.00
11	Lower shaft seal bushings (Part 37)	1	Set	2,300.00	4,000.00	2,300.00	1,200.00
12	Four impeller wearing rings for all four stages (Part 32)	1	Set	10,500.00	9,800.00	10,500.00	14,500.00
13	Four casing wearing rings for all four stages (Part 33)	1	Set	10,500.00	24,500.00	10,500.00	11,000.00
14	Three interstage shaft sleeves (Part 30)	1	Set	9,600.00	11,000.00	9,600.00	10,000.00
15	Three interstage bushings (Part 31)	1	Set	8,000.00	8,200.00	8,000.00	7,400.00
16	Balancing labyrinth (Parts 27 and 28)	1	Pair	14,000.00	22,000.00	14,000.00	15,400.00
17	Spare nuts, bolts, gaskets, keys, pins and other miscellaneous components for one pump	1	Lot	10,000.00	14,500.00	10,000.00	4,000.00
	TOTAL			$7,144,255.00	$6,349,998.00	$6,806,707.00	$7,719,035.00

EVALUATION OF BIDS

FOUR VERTICAL CENTRIFUGAL PUMPS FOR

TEHACHAPI PUMPING PLANT--SPEC. NO. 67-56

		ALLIS CHALMERS/ SULZER BROS.	BALDWIN-LIMA-HAMILTON/ J. M. VOITH	NEWPORT NEWS SB&DDCO/ ESCHER WYSS
(1)	Comparative Prototype Efficiency (percent)	92.4	92.2	91.3
(2)	Departure from highest comparative prototype efficiency (percent)	---	0.2	1.1
(3)	Departure from 0.2% "dead band" or "evaluated difference" (percent)	---	---	0.9
(4)	$88,000 times each 0.1 percent given in line (3)	---	---	$792,000
(5)	BID (Total from Abstract of Bids)	$6,349,998	$6,806,707	$7,719,035
(6)	EVALUATED BID (line (4) + line (5))	$6,349,998	$6,806,707	$8,511,035
		LOW BIDDER AND CONTRACTOR		

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES

CONTRACT FOR
FURNISHING AND INSTALLING
FOUR VERTICAL CENTRIFUGAL PUMPS
FOR
TEHACHAPI PUMPING PLANT
STATE WATER FACILITIES
CALIFORNIA AQUEDUCT
TEHACHAPI DIVISION
KERN COUNTY, CALIFORNIA

SPECIFICATION NO. 67-56

CONTRACT NO. 356700

THIS CONTRACT, made in duplicate this ________25th________ day of _____October_______, 1967, in accordance with the provisions of the State Contract Act and other applicable laws of the State of California, between the State of California, acting by and through its Department of Water Resources, hereinafter called the Department, and ________________________________

_______________Allis-Chalmers Mfg. Co.______________________________

____

____

____

hereinafter called the Contractor;

WITNESSETH, That the Department and the Contractor mutually agree as follows:

ARTICLE I.—This contract includes and incorporates by this reference the notice to contractors and Contractor's bid for the above named project, the contract bonds furnished by the Contractor pursuant to his bid and attached hereto, the drawings and specifications for such project, all addenda to the above documents, and all authorized changes herein. All definitions stated in the Standard Provisions of the specifications shall apply herein.

ARTICLE II.—The Contractor shall provide and furnish, except as otherwise expressly provided in the specifications, all materials, equipment, labor, methods, processes, construction materials and equipment, tools, plants, supplies, power, water, transportation and other things necessary to complete in a good and workmanlike manner, in accordance with the drawings, specifications and all other parts of this contract, and to the satisfaction of the Engineer, all of the facilities specified, indicated, shown, or contemplated by the drawings, specifications and other parts of this contract as comprising and necessary for completion of the above named project, and shall perform all other obligations imposed upon him by this contract.

ARTICLE III.—The Department shall pay to the Contractor, and the Contractor shall accept, as full compensation for performance of his obligations under ARTICLE II and for all risks and liabilities in connection therewith, the prices set forth in the Contractor's bid, all in accordance with and subject to the express terms and conditions of the specifications, the Contractor's bid, and other parts of this contract, and the Department shall perform all other obligations imposed upon it by this contract.

ARTICLE IV.—This contract shall apply to and bind the successors and assigns of the parties hereto.

IN WITNESS WHEREOF, the parties hereto have executed this contract as of the 25th day of Oct, 1967.

STATE OF CALIFORNIA
DEPARTMENT OF WATER
RESOURCES

William R. Gianelli
WILLIAM R. GIANELLI
Director of Water Resources

By____________________

ALLIS-CHALMERS MANUFACTURING COMPANY
Contractor

By R. C. Heyrman
R. C. HEYRMAN
ASSISTANT TREASURER
Title

APPROVED:

Alfred R. Golzé
Deputy Director, State Water Project

As To Funds

R. C. Towner
As To Legal Form and Sufficiency

I hereby certify that I have examined the within contract and find the same to be in accordance with the provisions of the State Contract Act.

THOMAS C. LYNCH
Attorney General of the State of California.

By August J. Emmerich
Deputy Attorney General

Dated November 10, 1967

V. EXCERPTS FROM DMJM FINAL REPORT ON COMPETITIVE MODEL TEST PROGRAM

THE RESOURCES AGENCY OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES

TEHACHAPI PUMPING PLANT

RESEARCH AND DEVELOPMENT PROGRAM

FINAL REPORT

ON THE

COMPETITIVE MODEL TEST PROGRAM FOR DEVELOPMENT OF THE TEHACHAPI PUMPS

OCTOBER 31, 1967

VOLUME I

DANIEL, MANN, JOHNSON, & MENDENHALL
Engineering Division
Los Angeles, California

MOTOR-COLUMBUS
Associate Consultants
Baden, Switzerland

I. INTRODUCTION

As consultants to the Department of Water Resources, Daniel, Mann, Johnson, & Mendenhall, and our associated European firm, Motor-Columbus, engaged in a Phase I development program wherein studies were made of pumping requirements for the Tehachapi plant and pump model studies were conducted with one of the main objectives being to determine the optimum lift system for the Tehachapi crossing and the corresponding type of pumps to be used. This effort covered a period of approximately three years and was culminated in a DMJM/MC Final Report submitted in May 1966, which included recommendations for the technical sections of the procurement specification for the Tehachapi pumps. During the spring of 1966 consideration was being given to a possible model competition to insure obtaining the most efficient pumps, or, more exactly, the best value in pumps considering both efficiency and procurement cost. Late in May 1966 the Department decided to proceed with a pump model competition and DMJM's consulting agreement with the Department was extended to permit administration of the program. The competitive model program was designated as Phase II of DMJM's Tehachapi R and D program, and this report is the final report for the Phase II effort.

The type of pump required for the Tehachapi plant will be one of the largest ever built. With the plant requiring 14 of these 76, 000 horsepower pumps such that ultimately 1, 000, 000 horsepower will be consumed, the value of efficiency related to operational costs is highly significant. Also, the value of the reliability of the plant and the pumps is nearly beyond comprehension. For these reasons, great care and effort went into the selection of the 4-stage pump type (Phase I of the program), and no less care and effort went into the competitive model program. Thus, it was decided right at the start to use the largest models practical in the competition to insure the least amount of unknown creeping into the scaling of model to prototype performance conditions. In speaking of "large" models, the physical size and testing head must both be taken into account. (Test rotative speed is directly related to test head.) Industry experience and more specific experience gathered on the Phase I model testing efforts were employed along with consideration of model construction problems and test lab capability to arrive at a basic minimum size and test condition for the models. A minimum impeller diameter of 15 inches was specified (resulting in prototype to model scale ratios of about 4. 75 to 1), and nearly full prototype head was to be required for the official test. As it turned out, the NEL dynamometer was limited to discrete test speeds of 250 rpm increments and so 2750 rpm was chosen for the "official" competitive test speed which produced very nearly full prototype head. Thus, the model size and the 2750 rpm test speed were basic controlling factors in the model design and test program.

Special mention is made of these facts as those readers having no previous knowledge of this program may wonder as to how these factors were established. The discussion throughout this report starts from this basic fixation on the model size and is not questioned in terms of the cost of the relatively large size models or the elaborate nature of the test equipment and procedures.

Similarly, the best obtainable accuracy of the testing for the competition and the prediction of prototype efficiency is considered of value beyond normal testing costs and so no efforts were spared in attempting to improve the accuracy of the work. The National Engineering Laboratory undoubtedly exceeded all previous standards for accuracy of pump testing.

II. SUMMARY & CONCLUSIONS

Three pump models meeting the design requirements for the Tehachapi pumps (Specification 67-24) were fabricated and development tested by the European partners of the three pre-qualified consortia. The models were sent to the National Engineering Laboratory in Scotland for "independent laboratory tests" where testing was completed within the program schedule. The official results were held in the custody of DMJM and submitted to the Department of Water Resources on the morning of the bid opening, October 4, 1967. The results of the bid opening are presented in Table II-1 and these results are the essential product of the test program.

The two top efficiencies were within the "dead band" and so the contract awards were determined by price alone. The value of the competitive program is manifested as follows:

1. The prototype pump efficiency that will be realized is nearly a full percent greater than what could be proven prior to the start of the program. The 4 stage pump model tested prior to this program had a predicted prototype efficiency of 91.3% compared to the currently determined 92.2% for the B-L-H/Voith pump and to the 92.4% value which was achieved by A-C/Sulzer. Evaluating the gain in efficiency by the $22,000 per 0.1% efficiency per pump unit used in the bid evaluation, the savings in power cost due to the improvement in efficiency far exceeds the cost of the model program.

2. The competing firms were required to develop their models to the point of meeting rather close tolerances for the pump head and flow rate. With this done prior to award of a prototype contract, the Department can be assured of receiving pumps with perfected hydraulic design. There need be no delays in prototype fabrication due to "research" to adjust pump performance characteristics.

3. The two firms receiving prototype construction awards successfully developed pumps to meet restricting cavitation criteria. Both of the pump models demonstrated ability to perform at the Tehachapi plant suction head setting corresponding to a suction specific speed value of 7000 virtually free of cavitation. So, the Department can be assured that these highly efficient pumps will not suffer cavitation problems in service.

4. The pump models are immediately available for testing for operational characteristics that will be useful in establishing plant operational procedures and they can be used along with the templates and dimensional gauges produced during model fabrication to assure the prototype pumps will be hydraulically homologous to the models.

III. PROGRAM HISTORY

A. Initiating the Program

At the time the decision was made to proceed with the competitive testing, the procurement schedule for the Tehachapi pumps was reaching the critical point in the overall aqueduct schedule. So, the competitive test program had to be performed rapidly and with minimum delay in getting underway. DMJM prepared a specification for the model fabrication and testing based on the results of a meeting in Baden, Switzerland, wherein all model manufacturers were invited and took part in a determination of the "ground rules" for the competition. By July 1, 1966, model manufacturing contracts and an instruction to proceed were sent to the three pre-qualified bidders:

1. Allis-Chalmers Manufacturing Co.
   Milwaukee, Wisconsin
   with
   Sulzer Brothers Limited
   Winterthur, Switzerland

2. Baldwin-Lima-Hamilton Corporation
   Philadelphia, Pennsylvania
   with
   J. M. Voith GMBH
   Heidenheim, Germany

3. Newport News Shipbuilding and Dry Dock Company
   Newport News, Virginia
   with
   Escher Wyss Limited
   Zurich, Switzerland

Thus, the model fabrication was underway and steps were then taken to select the independent model testing laboratory and plan out the remainder of the program. In Table III-1, the principal events of the program are listed. Greater detail of the program planning is presented in the following paragraphs.

B. The Baden Agreement and Model Contractor Negotiations

As mentioned above, in order to save time in initiating the program such that model construction could begin as soon as possible, a manufacturers' conference was called and held in Baden, Switzerland, on June 7, 1966. The joint meeting was for the purpose of arriving at an acceptable set of rules for the procurement and evaluation of the models. The minutes of this meeting were drafted into a concise report and copies were distributed to all those attending for them to sign as concurring with the conclusions reached. The list of attendees is given on the first page of the report which has since become known as the "Baden Agreement". All U. S. and European firms and other attendees signed copies which are on file at DMJM and at the Department of Water Resources in Sacramento. There were some letters expressing dissatisfaction with certain points in the Agreement, but all accepted its terms.

A copy of the Baden Agreement in original form is presented in Appendix I. The only major deviation in the performance of the program from the conditions established in the Baden Agreement resulted from the Department's ruling that bids could not be received before start of testing and held in escrow till after testing was complete. (See Paragraph C. following.)

Following the joint meeting in Baden, private meetings were held with each of the three manufacturing consortia, and model cost and delivery information was solicited. The prices they later submitted were not too different, ranging upward from $130,000. A flat figure of $130,000 was later offered to all three, and they all accepted. BLH/Voith quoted ten months delivery time whereas AC/Sulzer and NN/Escher Wyss quoted eleven months. Earlier estimates on the schedule had been ten months or less. Since the Tehachapi pump procurement schedule had become a critical item on the overall Aqueduct schedule and since all pump models could not be tested at once anyway, it was decided to accept a ten month delivery from BLH/Voith and eleven months from the other two. Although it was hoped that all three consortia would have equal conditions under which to work, the time schedule was considered so important that this exception was made.

C. <u>Model Contracts and the Model Specification</u>

On June 29, 1966, contract forms, a model specification, and a preliminary issue of the prototype specification technical sections were completed and sent to the three bidders.

In Appendix II, the contract form, the model specification and Amendment I are reproduced.[1] The documents were identical for all three firms except that the BLH/Voith delivery time was 300 days (10 months) whereas the AC/Sulzer and NN/Escher Wyss delivery times were 335 days (11 months). The cover letter sent with the contract documents gave the intended method of evaluation, and the pertinent section has been abstracted and presented in Appendix II. At the time the model contract documents were sent, a "letter of intent" was also sent to each Contractor authorizing them to proceed with design and fabrication. The letter was also sent in telegram form.

After the Contractors reviewed the model contract material, several comments were received which finally culminated in Amendment I which was sent to the Contractors on August 19, 1966, with instructions to sign and return with the contract forms. During the period of fabrication, the model specification drawings dealing with test stand installation were changed several times in attempts to better insure interchangeability of the models in the test rig. Otherwise, the only changes made were in the delivery schedules for both the models and reports which were brought about by the need for security and by minor technical difficulties that arose.

When the model program was being formulated, it was planned to have the model Contractors submit bids for the prototype fabrication prior to the performance of tests at the independent laboratory and then open the bids after all test results were obtained. In this manner, there would be no opportunity to adjust bids in speculation of the influence the model test results would have. All Contractors were agreed that this would be a fair method and it would appear that the State would receive the most realistic prices based on fabrication costs rather than on speculation. However, the Department's legal staff reviewed the contract proceedings and pointed out that under current California procurement laws, the bids could not be held; that is, up until the advertised bid opening date, bids could still be submitted and, consequently, there is no provision for a "holding period". DMJM was advised by a letter from Chief Engineer Alfred R. Golze' that the bids could not be held in "escrow" and the Contractors were notified of this situation. They all expressed dissatisfaction. However, there was nothing that could be done, and so it became necessary to

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[1] The preliminary issue of the technical sections of the prototype bid specification is not reproduced here as it is bulky and has been superseded by the Department's issuance of the Specification (No. 67-24).

impose very strict security on the dissemination of model test results so that any one Contractor would not be aware of the competitive advantage or disadvantage of the other Contractors and try to manipulate his bid accordingly. The security system was developed as a part of the NEL formal test procedure.

D. Independent Testing Laboratory Preparations

After the design and fabrication of the models was initiated, DMJM took up the problem of final selection of the test laboratory. The laboratory at NEL was known to have the capability for performing high speed testing of large models, but it was not certain if NEL would be available for a test of a primarily commercial nature. NEL was contacted and at the same time a survey of other laboratories was initiated. It was concluded that NEL had the only suitable facilities ready for use, and when the NEL administration agreed that the laboratory could be utilized, negotiations were carried out, and on October 5, 1966, a final discussion of the contractual requirements was held leading to the "Application for Test". A copy of the "Application" is presented in Appendix III along with a letter amendment that dealt with the introduction of the security program.

During the early part of 1967, NEL was engaged in preparing their laboratory specifically to test the 4 stage pump models and in the preparation of a test procedure report which would govern the methods of testing the models to insure equal treatment of the bidders in this competitive effort. DMJM personnel worked with the NEL staff in preparing the test procedure, and on March 16, 1967, copies of a draft of the report were distributed to the model manufacturers for comment.

During the period when the test procedure was being finalized, a "trial test" was performed on a large single stage model pump that was present at NEL. This model had been part of a Metropolitan Water District pump study and MWD kindly provided the model and the "trial test" to held prepare for the competitive test program. The trial test was useful in two principal respects: (1) Development of a completely computerized data processing system was aided; and (2) Equipment and instrument mechanical problems were discovered, and it was possible to make corrections prior to the start of the competitive tests.

During the week of April 17, 1967, an "Observers Briefing Meeting" was held at NEL and was attended by representatives from the model contractors, DWR, MWD, DMJM/MC, and the NEL staff assigned to the program. The purpose of the meeting was to thoroughly acquaint all participating and interested parties with the laboratory facilities and the procedures to be employed. This briefing session was quite successful in setting the stage for the testing. During the meeting, two prime areas of discussion developed. The first concerned the security system for safeguarding the test results. The problems of security were discussed at length and although the basic system developed by DMJM and NEL was adopted, there were several details changed or added which afforded improvement. To the best knowledge of the DMJM staff, there were no breeches of the security on the program.

The second prime area of discussion at the Observers Briefing Meeting was concerned with possible model failures and corrective actions that might be taken. In particular, the BLH/Voith group reported troubles with overloading of the model thrust bearing. Since all the models were to use the same brand and type of bearings for equalizing mechanical losses (as specified in the model specification), there was grave concern as to whether the models could be tested at high speed conditions. Subsequent to the meeting some research was done regarding the suitability and experience records with the selected thrust bearings and finally an improved lubricating grease was specified for use. As it turned out, no problems with bearings were experienced during the tests. However, the possibility of bearing or other mechanical failure occurring during the official tests at NEL prompted a major change in the test procedure and security handling of the data. It was arranged for the more severe tests (from a mechanical standpoint) to be performed in the order of increasing severity with the understanding that it might be necessary to accept lower speed tests for all models for purposes of the bid evaluation. Fortunately, it turned out that the essential maximum speed testing was accomplished for all models.

Following the Observers Briefing Meeting,the Test Procedure Report draft was revised and issued in final form in May 1967 just prior to the start of testing the first model.

The test procedure, operations, and results are fully documented in the NEL reports. Therefore, they are incorporated into this report as Volume II with no further editorial detail. The original laboratory data is not reproduced, however, simply because it is too voluminous -- essential computer input and output data is presented, and it provides the important results. The original data and all computer sheets are on file at NEL, and a complete copy set is filed in the DMJM project file.

TABLE III-1

TEHACHAPI PUMPING PLANT

COMPETITIVE MODEL PROGRAM

SCHEDULE OF EVENTS

DMJM JOB NO. 637-1-2

DATE	ACTIVITY
April 6, 1966	Joint meeting of the Tehachapi Crossing Consulting Board and the DMJM Technical Advisory Board for the discussion of the Tehachapi pump procurement.
April 22, 1966 May 6, 1966	Meetings of DWR, MWD and engineering consultants to discuss the Tehachapi procurement methods.
May 20, 1966	Discussion of lab testing of bidders' models at NEL with Director Warne present. Verbal instruction for DMJM to proceed with arrangements.
June 7, 1966	Bidders' conference held in Baden -- Minutes of conference known as "Baden Agreement" form basis for model construction and test contracts to which all firms agree.
June 27, 1966	Amendment to State-DMJM Agreement No. 352876 approved. Amendment provides for DMJM to contract with manufacturers for bidders' models; arrange for testing in an independent laboratory; and assist the state in evaluation of test results and bids for prototype pumps.
June 29, 1966	Model contract form (DMJM 637-1-2), model specification and preliminary issue of technical sections of prototype specification sent to pre-qualified bidders.
June 29, 1966	"Letter of Intent" (wire) sent to contractors authorizing them to begin prior to executing contract documents.
July 1, 1966	Beginning date for all three model contracts.

July 7, 1966	Start of negotiations with National Engineering Laboratory (NEL), East Kilbride, Scotland, for test laboratory.
August 19, 1966	Amendment I to contract form (DMJM 637-1-2) sent to all contractors.
September 13, 1966	Bidders' conference in Baden to discuss prototype specification and its invluence on the model designs.
September 14 & 15, 1966	Conference with NEL to discuss laboratory program and contract.
October 1, 1966	Prototype and model design report due. Newport News/Escher Wyss report received September 6, 1966. BLH/Voith report received October 5, 1966. AC/Sulzer report - received November 2, 1966.
October 10, 1966	Copies of NEL contract draft sent to Department for review and approval.
November 4, 1966	Submission to the Department by DMJM of a report entitled, "Status Report on the Bidders' Pump Models Program".
December 1, 1966	Department approval to proceed with NEL contract.
February 17, 1967	Final execution of NEL contract.
March 16, 1967	Test Procedure draft sent to contractors for review.
April 18-21, 1967	Observer Briefing Meeting at NEL.
May 1967	Test Procedure finalized and issued.
May 21, 1967	BLH/Voith model testing started.
June 1, 1967	BLH/Voith model testing completed.
June 18, 1967	AC/Sulzer testing started.
June 28, 1967	AC/Sulzer testing completed.
July 9, 1967	NN/Escher Wyss testing started.
July 17, 1967	Basic high speed tests completed but mechanical deterioration discovered.

August 14-16, 1967	Repeat of high speed tests with repaired model--repair not successful--testing concluded--data obtained prior to July 17 taken as official.
October 4, 1967	Test Results submitted by DMJM to DWR in Sacramento for bid opening.
October 4, 1967	Bid opening for 7 pumps - Specification No. 67-24.
October 16, 1967	Newport News/Escher Wyss test report received at DMJM.
October 16, 1967	Allis Chalmers/Sulzer test report received at DMJM.
October 18, 1967	Bid opening for 4 pumps - Specification No. 67-56.
October 19, 1967	B-L-H/Voith test report received at DMJM.
	NEL final report received by DMJM.
October 31, 1967	DMJM Final Report on the Competitive Model Program submitted to DWR.

IV. MODEL DEVELOPMENT

A. General

As shown by the model contract and specifications (Appendix II), each model contractor was required to design and build a four-stage model, test it in his own laboratory, and do such development as he deemed necessary and then submit the model to the independent laboratory for the official testing. Documentation required of the contractors consisted of a design report and a test report. The test report was due following the official independent laboratory tests and was to include a comparison of the contractor development testing results with the NEL results. The design and test reports for each of three manufacturing consortia are reproduced in this section, and they serve to tell the story of the model development. The reports are grouped under the contractor consortium name.

Also included are two sets of data gathered or checked on the spot by DMJM/MC. The two items are: (1) a dimensional check of the basic model dimensions and the model sealing surfaces to guarantee compliance with the specification ; and (2) a further check on basic model dimensions and a check of construction templates for use in the homologous scaling of the model parts to the prototype parts.

B. Model Pump Inspection

The first inspection was conducted by the Engineer (DMJM/MC) and carried out in the manufacturer's plant prior to the model pump's shipment to the independent laboratory. Clearances of all sealing surfaces (i. e., wear rings, balancing labyrinth and shaft seals) were measured and found to be within the requirements of the specification. Dimensions of the impeller inlet and discharge area were measured and recorded.

At the conclusion of the bidders model tests at NEL, each model pump was sealed by the Engineer and shipped to the manufacturer's workshop. Later the seal was broken in the presence of the Engineer, and each pump was disassembled in order to conduct a blade template inspection. This inspection consisted of recording the deviations between the template and each blade of the model pump and identifying the specific templates controlling the blade contours and angles. In cases where the manufacturers had made alternate parts, the model assemblies were checked for identification of the parts actually used in the test and some dimensions were further checked to insure compliance with the model specification.

At the conclusion of all dimensional checking, the Engineer was satisfied that all models had been in proper dimensional order for the official tests and that the necessary dimensional data was available for the construction of prototype pumps.

C. Contractor Test Reports.

The test reports show that each consortium worked diligently to perfect his model. It is also demonstrated that in each case the official efficiency results obtained at NEL and the contractor obtained results (which due to differences in laboratories and laboratory capabilities were not gathered under similar conditions) are closely in agreement. This close agreement leaves no reason to doubt the validity of the official tests.

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